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Stock Assessment and Restoration of the Afognak Lake Sockeye Salmon Run, 2008

by

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and

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July 2009

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Beginning in 2001 the Afognak Lake sockeye salmon *Oncorhynchus nerka* runs substantially declined. Concerns expressed by local subsistence users to the Alaska Department of Fish and Game and the US Fish and Wildlife Service Office of Subsistence Management prompted an investigation of the lake's rearing environment in 2003 followed by subsequent annual studies. This report provides the 2008 fishery and limnology results from the Afognak Lake system and fulfills annual reporting requirements to the US Fish and Wildlife Service Office of Subsistence Management, the funding agent for this project (project 07-401).

During 2008, 12,698 sockeye salmon smolt were captured using a Canadian fan trap operated from 16 May to 3 July. An additional 10,766 smolt were estimated to have been captured when the trap was not fishing during a five day flood event. Using mark-recapture techniques, we estimated that 196,941 sockeye salmon smolt (95% CI 148,046 – 245,835) emigrated from Afognak Lake. The population was estimated to be composed of 92,018 age-1. and 104,923 age-2. smolt. Age-1. smolt had a mean weight of 3.4 g, a mean length of 75.9 mm, and a mean condition factor of 0.76. Age-2. smolt had a mean weight of 4.0 g, a mean length of 81.7 mm, and a mean condition factor of 0.73.

Five limnology surveys were conducted in Afognak Lake from May to September, 2008. Seasonal physical parameters and water chemistry values were generally consistent with historical data collected from Afognak Lake; however, phosphorus concentrations in 2008 were below historically low phosphorus levels. Zooplankton levels in 2008 also approached historical lows with a seasonal density of 108,462 animals m^{-2} and the biomass 110.9 mg m^{-3} with cladocerans comprising 59.6% of the sampled zooplankton. The cladoceran *Bosmina* was the most abundant zooplankter, while *Epischura* was the most abundant copepod.

Key words: Afognak Lake, Litnik, age, emigration, escapement, Kodiak Island, Oncorhynchus nerka, smolt, sockeye salmon, subsistence harvest, trap, zooplankton.

INTRODUCTION

DESCRIPTION OF STUDY AREA

The Afognak Lake system is located on the southeast side of Afognak Island approximately 50 km northwest of the city of Kodiak (Figure 1). The Afognak Native Corporation owns the land surrounding the Afognak Lake system down to tidewater. Afognak Lake (58^{o} 07' N, 152^{o} 55' W) lies 21.0 m above sea level, is 8.8 km long, has a maximum width of 0.8 km, and has a surface area of 5.3 km^2 (Schrof et al. 2000; White et al. 1990). The lake has a mean depth of 8.6 m, a maximum depth of 23.0 m, and a lake-water residence time of 0.4 years (Figure 2). Runoff from Afognak Lake flows in an easterly direction into the 3.2 km long Afognak River, which in turn flows into Afognak Bay, which is part of the Alaska Maritime National Wildlife Refuge and where most subsistence fishing occurs.

In addition to sockeye salmon *Oncorhynchus nerka*, other fish species in the Afognak Lake drainage include pink salmon *O. gorbuscha*, coho salmon *O. kisutch*, rainbow trout (anadromous and potamodromous) *O. mykiss*, Dolly Varden *Salvelinus malma*, three spine stickleback *Gasterosteus aculeatus*, and coastrange sculpin *Cottus aleuticus* (White et al. 1990). Chinook *O. tshawytscha* and chum *O. keta* salmon have been observed in the Afognak River on occasion, but have not established discernable spawning populations (White et. al 1990).

BACKGROUND

Harvest, Management and Enhancement

A counting weir was first established just below the lake outlet on the upper reaches of the Afognak River in 1921 and was operated intermittently through 1977. Since 1978 to the present, escapement data has been collected annually. In 1986, the weir was relocated to its current location, 200 meters upstream of the mouth of Afognak River, and Alaska Department of Fish and Game (ADF&G) has maintained annual weir counts in conjunction with sockeye salmon age, length and sex (ALS) sampling (Foster *In press*). Catch data have been documented through the ADF&G commercial landing fish ticket system, statewide sport fish surveys, and return of subsistence fishing permits since the late 1970s (Dinnocenzo and Caldentey 2008).

Since 1978, when ADF&G began recording subsistence harvest data, the Afognak Lake sockeye salmon run has provided for the largest subsistence salmon fishery on Afognak Island and the second largest in the Kodiak Archipelago (Baer et al. 2009). Local villagers from Port Lions, Ouzinkie, Afognak Village, and Kodiak area residents have traditionally harvested fish in Afognak Bay (Figure 1). The subsistence fishery is prosecuted within the boundaries of the Alaska Maritime National Wildlife Refuge.

Prior to 2005 the Afognak Lake sockeye salmon escapement goal range was 40,000 to 60,000 fish (Nelson and Lloyd 2001). Escapements in 1987 and 1988 did not reach the lower end of the range, and little commercial fishing effort was directed at this stock through the mid to late 1980s (White et al. 1990). In the mid 1980s, Kodiak Island residents surveyed by the Kodiak Regional Planning Team (KRPT) indicated that sockeye salmon were the preferred species for commercial and subsistence fishers in the area (KRPT 1987). These results, coupled with the declining sockeye salmon production from Afognak Lake, resulted in the system being listed by the KRPT and Kodiak Regional Aquaculture Association (KRAA) as the highest priority sockeye salmon enhancement project on Afognak Island. In 1987, the ADF&G, in cooperation with KRAA, initiated pre-fertilization fisheries and limnological investigations at Afognak Lake (Honnold and Schrof 2001; Schrof et al. 2000; White et al. 1990). Results of these investigations indicated that sockeye salmon production was limited by rearing capacity (White et al. 1990). Nutrient enrichment was recommended and then implemented in 1990 to increase primary and secondary production, which was intended to increase sockeye salmon rearing capacity in the lake. The ADF&G and KRAA had fertilized the lake (1990-2000) and stocked juveniles (1992, 1994, 1996-1998) into Afognak Lake to enhance the sockeye salmon run (White et al. 1990). As part of the evaluation process, limnological data (phosphorus, nitrogen, chlorophyll *a*, and zooplankton) were collected three years prior to, during, and three years after fertilization activities.

Adult sockeye salmon from Afognak Lake were screened for disease in 1987 and 1988 as part of an evaluation of the stock as a candidate for an early-run brood source for future KRAA enhancement projects (Schrof et al. 2000; White et al. 1990). The Afognak Lake sockeye salmon stock was selected as a brood stock for barren lake stocking projects on Afognak Island, with the first fish stocked in Little Waterfall, Hidden, and Crescent Lakes in 1992 (Duesterloh and Byrne 2008). Hatchery survivals were higher than anticipated in 1992 and resulted in more fry being available than had been planned. Rather than increasing stocking levels into the barren lakes, which had not been stocked previously, the ADF&G allowed KRAA to stock the excess fry back into Afognak Lake. Although the escapement in 1992 (and from 1989 to 1991) exceeded the sustainable escapement goal, stocking a fairly small number of juveniles (less than 500,000) was considered acceptable as long as the lake fertilization program continued and zooplankton (primary forage for juvenile sockeye) levels remained stable. Afognak Lake stocking was repeated in 1994, and from 1996 to 1998. To alleviate concerns of increasing the predation pressure exerted by stocked fry on the zooplankton population lake fertilization was continued. In 1999, the ADF&G wanted the KRAA to follow the established egg take goals in order to avoid stocking excess fry into Afognak Lake (Honnold et al. 1999). The number of sockeye salmon eggs that could be taken from Afognak Lake by KRAA was reduced, and fertilization of Afognak Lake was also discontinued after 2000 (Honnold and Schrof 2001).

Beginning in 2000, the Alaska Board of Fisheries adopted two policies into regulation to ensure that the state's salmon stocks would be conserved, managed, and developed using the sustained yield principle. In 2000 the Policy for the Management of Sustainable Salmon Fisheries (5 AAC 39.222) was adopted and in 2001 the Policy for Statewide Salmon Escapement Goals (5 AAC 39.223) was put into regulation.

Two important terms defined in the Policy for the Management of Sustainable Salmon Fisheries are:

> "*Biological escapement goal* (BEG): the escapement that provides the greatest potential for maximum sustained yield (MSY)" and,
>
> "S*ustainable escapement goal* (SEG): a level of escapement, indicated by an index or an escapement estimate, that is known to provide for sustained yield over a 5 to 10 year period, used in situations where a BEG cannot be estimated due to the absence of a stock-specific catch estimate."

Afognak Lake sockeye salmon runs substantially declined in 2001 and subsequent escapements from 2002 through 2004 were below the established sustainable escapement goal (SEG) range of 40,000 to 60,000 sockeye salmon (Baer et al. 2009; Caldentey 2009; Dinnocenzo and Caldentey 2008; Honnold et al. 2007). As a result of these poor runs, the commercial sockeye salmon fishery in the South East Afognak Section (which includes all of Afognak Bay and surrounding waters; Figure 1) was closed in 2001 and commercial fishing remained closed until 2005 when a five day opening occurred and 356 fish were harvested. Sport fishing restrictions were also implemented in 2001, and in-season closures and reduced bag limits have occurred each year through 2004. In conjunction with commercial and sport fishing closures, State and Federal managers closed subsistence fishing in early June during the 2002 season, and in-season closures have occurred each year through 2004 in an attempt to achieve the escapement goals for sockeye salmon into Afognak Lake.

In 2004, using the new sustainable management policies, a team of ADF&G biologists re-evaluated the existing Afognak Lake sockeye salmon escapement goal. The team recommended changing the escapement goal from an SEG of 40,000 to 60,000 sockeye salmon (Nelson and Lloyd 2001) to a BEG of 20,000 to 50,000 sockeye salmon (Nelson et al. 2005). The recommendation was based on analysis of Ricker spawner-recruit model and limnology data, excluding data from years in which the lake was fertilized. In January 2005, the Directors of Commercial Fisheries and Sport Fish Divisions approved these recommendations. In 2007, the escapement goal was reevaluated with three additional years of data and was recommended to remain unchanged at a BEG of 20,000 to 50,000 fish (Honnold et al. 2007). Escapements during the last eight years have been just below (2002 and 2004) to just above (2001, 2003, 2005-2008) the lower end of the new BEG range (Table 1). However, the Policy for Sustainable Salmon Management instructs the ADF&G "to maintain evenly distributed salmon escapements within the bounds of the BEG."

The sockeye salmon commercial fishery in the Southeast Afognak Section has remained closed since 2005. The sport fishery remained open throughout the 2005 and 2006 seasons without any restrictions but was closed again in 2007. The subsistence fishery remained open throughout the 2005 and 2006 seasons with minimal harvests, while a closure occurred in 2007 through the month of July. Although the subsistence fishing closures restricted harvest of sockeye salmon and caused fishing efforts to shift to other systems, subsistence salmon fishing has been allowed every year in Afognak Bay for pink and coho salmon starting 1 August. Subsistence harvests in Afognak Bay from 1990 to 2008 have ranged from 451 (2006) to 12,412 (1997) sockeye salmon (Table 1). The smallest annual sockeye salmon subsistence numbers on record are from the most recent seven years (2002-2008).

Juvenile Production and Limnological Investigations

Juvenile production studies have been conducted in conjunction with limnological investigations at a number of sockeye salmon systems in the Kodiak archipelago (Barrett et al. 1993a, 1993b; Coggins 1997; Coggins and Sagalkin 1999; Edmundson et al. 1994a, 1994b; Honnold 1997; Honnold and Edmundson 1993; Kyle et al. 1988, 1990; Kyle and Honnold 1991; Sagalkin 1999; Sagalkin and Honnold 2003; Schrof et al. 2000; Swanton et al. 1996; White et al. 1990). Some of these studies estimated smolt abundance and size by age through trapping and mark-recapture techniques. Several studies also counted the entire smolt emigration by use of a weir and trap. Rearing juveniles in lakes were enumerated using hydroacoustics and trawl surveys. Smolt abundance and size studies provide estimates of overall freshwater survival, covering the time between egg deposition in the gravel and smolt emigration to the ocean.

The ADF&G had little information on Afognak Lake juvenile sockeye salmon during their freshwater life history stage, when sockeye salmon mortality rates are usually greatest (Burgner 1991). Prior to 2003, ADF&G efforts to collect juvenile sockeye salmon data from Afognak Lake were met with limited success (Schrof and Honnold 2003). Estimates of lake rearing juveniles using hydroacoustics proved inaccurate due to the presence of large numbers of sticklebacks. Due to difficulties associated with species separation, hydroacoustic surveys were discontinued after 1995. Smolt abundance data were collected through the use of smolt traps in 1990 and 1991, but reliable smolt estimates were not obtained due to low trap efficiencies identified during mark-recapture trials, which were probably caused by poor trap design. In 1992, funding for the mark-recapture project was discontinued and only the collection of smolt age, weight, and length data were continued. Further funding reductions resulted in smolt age, weight, and length (AWL) data collection being limited to one annual sample after 1995. It was not until 2003 that a smolt and lake study was reinitiated (Honnold and Schrof 2004).

After Afognak Lake experienced poor runs and fisheries closures in 2002, local subsistence users, represented by the Kodiak-Aleutian Islands Regional Advisory Council, Kodiak Fish and Game Advisory Committee, and Kodiak Tribal Council, contended that a continued closure of the Afognak system would make it more difficult for local residents to harvest sockeye salmon and would shift fishing effort to small sockeye salmon runs in the area and the Buskin River. The Regional Advisory Council, Kodiak Advisory Committee, and Kodiak Tribal Council informed the ADF&G and U.S. Fish and Wildlife Service that the Afognak Lake sockeye salmon run failure constituted an emergency situation for their constituents. In response to this problem, the ADF&G received funding through the Office of Subsistence Management (OSM) Fishery Resources Monitoring Program to determine the feasibility of estimating sockeye salmon smolt production from Afognak Lake. This initial feasibility study, conducted in 2003, showed that sockeye salmon smolt could be effectively trapped in Afognak River and their abundance reliably estimated using mark-recapture techniques (Honnold and Schrof 2004).

In addition to smolt abundance and size data, additional information on the rearing conditions within Afognak Lake were needed to determine what other factors may be affecting sockeye salmon production. A lake's physical parameters (solar illumination, temperature, and dissolved oxygen) greatly affect nutrient cycling (Schlesinger 1991). Lake nutrients, specifically phosphorous and nitrogen, are prerequisites for photosynthesis and their concentrations can be used to assess the potential for primary production within a system (Spalinger and Bouwens 2003). Chlorophyll-*a* levels are indicators of the standing crop of primary producers that provide food for zooplankton, which are prey for sockeye salmon. Estimating zooplankton population attributes are crucial to understanding the progression of a lacustrine food chain. Zooplankton abundance, individual size, and species composition can be regulated from the bottom-up by phytoplankton availability (Stockner and MacIsaac 1996), or from the top-down by predation pressures such as grazing by juvenile sockeye salmon (Kyle 1992).

Based on the findings from the 2003 feasibility study, the OSM provided funding for a three-year study (2004-2006) that enabled the continuation of smolt assessment work, examination of rearing and spawning capacity, and estimation of the sockeye salmon production potential of Afognak Lake. Sockeye salmon freshwater production is also limited by the amount and quality of available spawning habitat (Honnold and Edmundson 1993; Willette et al. 1995). In 2005, spawning habitat surveys were conducted on the tributaries of Afognak Lake resulting in an estimated total tributary capacity of 15,297 spawners. The lake shoal spawning capacity was more difficult to assess (Baer et al. 2007). Prior studies have reported peak shoal spawner counts ranging from 35,811 to 70,853 (White et. al. 1990; from the unpublished 1984 Migratory Timing of the primary Spawning populations of red salmon at Afognak Lake by Mark T. Willette, available at ADF&G Kodiak). A final report in 2007 consolidated historical fishery and limnological data, provided results of a sockeye salmon escapement goal review and production analysis conducted from 2004 to 2006, and documented the final results of the project. The three year study indicated that rearing conditions within Afognak Lake appeared to be stable or improving and zooplankton abundance did not suggest overgrazing. Favorable rearing conditions were reflected in the relatively high condition factor of the smolt (>0.75) that enabled most juveniles (86%) to emigrate at age-1.

Continued analysis of Afognak Lake and annual smolt emigration studies were determined to be of high importance to evaluate if there were changes in the nutrient-food web dynamics (e.g., if the structure of consumer communities have modified nutrient transfer along the food web) and how these changes may have affected the growth and production of the juvenile sockeye salmon emigrating from Afognak Lake. Recognizing the importance of continued analysis on Afognak Lake sockeye salmon production, the OSM extended funding to ADF&G for an additional three-year study (2007-2009). This annual report summarizes the 2008 fishery and limnological results associated with the Afognak Lake system.

OBJECTIVES OF THE PROJECT

1. Estimate the number, age, and average size at age of sockeye salmon smolt emigrating from Afognak Lake for 2007 through 2009.
    - Estimate the number (achieving 25% relative error) with a 95% confidence.
    - Estimate the age proportion within d=0.03 of the true proportion with 95% confidence.
    - Estimate the average length within 0.5 mm of the true average length and the average weight within 0.25 g of the true average weight with a 95% confidence.

2. Evaluate the water chemistry, nutrient status, and plankton production of Afognak Lake from 2007 to 2009.
3. Assess the rearing conditions for juvenile sockeye salmon in Afognak Lake based upon completion of objectives 1 and 2.

METHODS

SMOLT ASSESSMENT

Trap Deployment and Assembly

An inclined-plane Canadian fan trap (Ginetz 1977; Todd 1994) was installed on 16 May 2008 approximately 32 m upstream from weir site. The trap was positioned towards the middle of the river, where water velocity was great enough to make it difficult for smolt to avoid capture (Figure 3). A live box (1.2 m x 1.2 m x 0.5 m) was attached to the cod end of the trap, and the entire trapping device was suspended from cables attached to a come-alongs which were fixed to each stream bank. The trap was secured to an aluminum pipe frame, which allowed the vertical trap position to be adjusted in response to water level fluctuations. Perforated (3.2 mm) aluminum sheeting (1.2 m x 2.4 m) supported by a Rackmaster®[1] pipe frame was placed at the entrance of the trap in a "V" configuration to divert smolt into the mouth of the inclined plane trap (Figure 3). Trapping ceased, and the trap was removed from the river on 4 July after smolt abundance declined and the number captured was less than 100 smolt per day for three consecutive days. Detailed methods for trap installation, operation, and maintenance are described in Baer (2008).

Smolt Enumeration

Smolt were captured in the trapping system and held in the attached live box until they were counted. During the evening (2200 to 0800 hours), the live box was checked every one to two hours, depending on smolt abundance. During the day (0801 to 2159 hours), the live box was checked every three to four hours. All smolt were removed from the live box with a dip net, counted, and either released downstream of the trap or transferred to an in-stream holding box for sampling and marking. Estimates of theoretical trap catch, which were derived from time series analysis (Heather Finkle, fisheries biologist, Alaska Department Fish and Game, personal communication), were applied to days when trapping could not occur due to uncontrollable flooding events in 2008. Species identification was made by visual examination of external characteristics (Pollard et al. 1997). All data, including mortality counts, were entered on a reporting form each time the trap was checked.

Trap Efficiency and Population Estimates

Mark-recapture experiments were performed to measure smolt trap efficiency (*E*). Sockeye salmon smolt were collected, marked with Bismark Brown Y dye, and released about once per week as well as when changes were made to the trapping system. Based on smolt studies at Akalura Lake (Coggins and Sagalkin 1999; Sagalkin and Honnold 2003), we attempted to achieve trap efficiencies between 15 to 20%. To estimate the desired trap efficiency and be within the relative error (r) of 25% in estimating total abundance, we needed to mark 600 smolt

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[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

for each experiment (Carlson et al. 1998; Robson and Regier 1964). Once collected, smolt were placed in an aerated 33-gallon trashcan filled with water and transported, in a trailer pulled by an all-terrain vehicle to the release site approximately 1,240 m upstream. At the release site, smolt were exposed to a continuously oxygenated solution of Bismark Brown Y dye (1.9 g of dye to 15 gallons of water) for 30 minutes. The smolt were then transferred to a holding box at the release site. Between 2100 and 2300 hours, most of the dyed smolt (~500) were randomly selected from the holding box, counted, and released across the width of the stream. The remaining dyed smolt (~100) were counted and left in the holding box for five days to estimate delayed mortality resulting from the capture and marking process. Dyed smolt from both groups that displayed unusual behavior (labored respiration, flared gills, side swimming, etc.) were removed from the experiment and released downstream of the trap. The proportion of smolt that died during the five day holding period was used to estimate the actual number of marked smolt available for recapture in the experiment (M_h). All dyed smolt recaptured at the trap site were counted and assigned to a recapture period, hereafter referred to as a stratum, which is the time period starting at the day of releasing dyed fish until the day before the next release and mark recapture event.

Trap efficiency for each stratum (h) was calculated by dividing the total number of dyed smolt recaptured by the number of dyed smolt released within the stratum:

$$E_h = \frac{(m_h + 1)}{M_h + 1}, \tag{1}$$

where

E_h = trap efficiency or smolt capture probability in stratum h,

M_h = number of marked smolt released in stratum h and adjusted for estimated delayed mortality,

m_h = number of marked smolt recaptured in stratum h.

A modification of the stratified Peterson estimator (Carlson et al. 1998) was used to estimate the number of smolt emigrating within each stratum:

$$\hat{U}_h = \frac{u_h (M_h + 1)}{m_h + 1}, \tag{2}$$

where

U_h = total number of smolt in stratum h, excluding marked releases and minus observed mortality, and

u_h = number of unmarked smolt recaptured in stratum h.

Variance of the smolt abundance estimate was calculated as,

$$v(\hat{U}_h) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2 (m_h + 2)}. \tag{3}$$

The estimate of $\hat{U}$ for all strata combined was estimated by

$$\hat{U} = \sum_{h=1}^{L} \hat{U}_h, \tag{4}$$

where L is the number of strata. Variance for $\hat{U}$ was estimated by

$$v\left(\hat{U}\right)=\sum_{h=1}^{L} v\left(\hat{U}_h\right), \tag{5}$$

and 95% confidence intervals were estimated from

$$\hat{U} \pm 1.96\sqrt{v\left(\hat{U}\right)}, \tag{6}$$

which assumes that $\hat{U}$ is asymptotically normally distributed.

Within each stratum *h*, the total population size by age class *j* was estimated as,

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \tag{7}$$

where $\hat{\theta}_{jh}$ is the proportion of age class *j* during each stratum *h*. Variance of $\hat{\theta}_{jh}$ was calculated using the standard variance of a population proportion (Thompson 1987). The variance of $\hat{U}_{jh}$ was calculated as,

$$v\left(\hat{U}_{jh}\right)=\hat{U}_h^{\,2} v\left(\hat{\theta}_{jh}\right)+\hat{U}_h v\left(\hat{\theta}_{jh}\right)^2 \tag{8}$$

The total number of emigrating smolt by age class was calculated by summing the individual strata. Variance of the total emigration estimates was calculated by summing the individual variances.

Age, Weight, and Length Sampling

Approximately 200 sockeye salmon smolt were sampled each statistical week to obtain AWL data. To reach the weekly total, daily samples of 40 sockeye salmon smolt were collected for five days within each statistical week. Smolt were collected throughout the night and held in the in-stream live box. The number of smolt collected each hour was proportional to emigration abundance. Forty smolt were randomly collected from those retained in the live box and sampled to obtain daily AWL data. After sampling, all smolt were released downstream from the trap.

Tricaine methanesulfonate was used to anesthetize smolt prior to sampling. Fork lengths were measured to the nearest 1 mm, and weights were recorded to the nearest 0.1 g. Scales were removed from the preferred area (INPFC 1963) and mounted on a microscope slide for age determination. After sampling, smolt were held in aerated buckets of water until they recovered from the anesthetic, and subsequently released downstream from the trap. Age was estimated from scales viewed with a microfiche reader at 60X magnification, and recorded in European notation (Koo 1962).

Condition factor (Bagenal and Tesch 1978), a quantitative measure of "fatness," was determined for each sampled smolt as:

$$K=\frac{W}{L^3}10^5, \tag{9}$$

where

K	=	smolt condition factor,
W	=	weight in g, and
L	=	snout to fork length in mm.

Life History-Based Population Estimates

We also estimated the number of smolt we expected to emigrate in 2008 based on escapements and what we felt were realistic life history-based assumptions of actual fecundity data and egg to smolt survival rates as reported from other clear water lake systems. This alternative method of estimating smolt emigration incorporated sockeye salmon escapement data from Afognak Lake, female fecundity data (egg abundance) from Afognak Lake, egg-to-smolt survival estimates, and age composition data from Afognak Lake to generate a theoretical smolt production estimate by year. Using parent spawning escapements in 2005 and 2006, we assumed a 1:1 sex ratio, an average egg deposition of 2,195 per female in 2005 and 2,077 eggs per female from 2006 (average number of eggs per female as determined from 2005 and 2006 Afognak Lake egg-take fecundity assessment by Pillar Creek Hatchery), 7% egg-to-fry survival (Drucker 1970, Bradford 1995 and Koenings and Kyle 1997), 21% fry-to-smolt survival (Koenings and Kyle 1997), and age composition data from the 2008 emigration samples.

The life history model was further refined by investigating a simple linear regression model utilizing recent years of age-1. and age-2. smolt outmigration relationships from 2003-2007. In constructing and evaluating the regression model, standard regression diagnostic procedures were used. The estimate from the regression model was only used where the slope of the regression was significantly different from zero ($P < 0.25$).

LIMNOLOGICAL ASSESSMENT

Lake Sampling Protocol

Five limnological surveys of Afognak Lake were conducted at approximately 4-5 week intervals from May to September, 2008. Collected data and water samples were returned to the ADF&G Near Island Laboratory and analyzed as described in Thomsen (2008). Two stations, marked with anchored mooring buoys and located with Global Positioning System (GPS) equipment, were sampled from a float plane during each survey (Figure 2). Zooplankton samples were collected at both stations, but water samples were only collected at Station 1. During each survey, water samples for general chemistry and nutrient analysis were collected at a depth of 1 m below the water's surface using a 4-L Van Dorn sampler. Each water sample was emptied into a pre-cleaned polyethylene carboy, which was kept cool and dark in the float of the plane until processed at the ADF&G laboratory in Kodiak. Vertical zooplankton hauls were made at each station using a 0.2 m diameter conical net with 153 µm mesh. The net was pulled manually at a constant speed (~0.5 m sec^{-1}) from approximately 2 m off the lake bottom to the surface. The contents from each tow were emptied into a 125-ml polyethylene bottle and preserved in 10% buffered formalin.

Temperature, Dissolved Oxygen, Light, Water Clarity and Euphotic Volume

Water temperature (°C) and dissolved oxygen (mg L^{-1}) levels were measured with a YSI® meter. Surface temperature readings were calibrated against a hand-held mercury thermometer.

Readings were recorded at half-meter intervals to a depth of 5 m, and then at one-meter depth intervals to the lake bottom. Results were categorized into spring (May-June), summer (July-August), and fall (September-October) sampling periods.

Measurements of photosynthetically active wavelengths (PAR) were taken with a Protomatic® submersible photometer sensitive to the visible spectrum range (400-700 nanometers). Readings were taken above the water surface, at the water surface, and at half-meter intervals below the water surface until reaching a depth of 5 m, and then at one-meter intervals until either the lake bottom or a depth equivalent to 1% of the subsurface reading was reached. The mean euphotic zone depth was determined (Koenings et al. 1987) for the lake and used in a model to estimate sockeye salmon fry production (Koenings and Kyle 1997). The vertical extinction coefficient for downward light (Kd, m^{-1}) was obtained from the relation:

$$I_z = I_o e^{-Kd} \text{ or } \ln I_z = \ln I_o - K_d z, \tag{10}$$

where

I_o	=	light penetration just below the surface (Wetzel and Likens 1991),
I_z	=	light penetration at *z* meters (Wetzel and Likens 1991), and
K_d	=	the linear regression coefficient of $\ln I_z$ against depth (z).

Assuming K_d is constant with depth, the mean euphotic zone depth, the depth at which 1% of the subsurface light remains, is given by $4.6/K_d$ (Kirk 1994).

One-meter temperature and dissolved oxygen profiles were compared to assess the physical conditions in the euphotic zones of the lake. Secchi disc readings were collected from each station to measure water transparency. The depths at which the disc disappeared when lowered into the water column and reappeared when raised in the water column were recorded and averaged.

Lake primary production potential for rearing juvenile sockeye salmon was assessed through a euphotic volume calculation (Koenings and Burkett 1987; Nelson et al. 2005). To calculate euphotic volume, the average mean euphotic zone depth was multiplied by the surface area (Afognak Lake = 5.3 km^2).

General Water Chemistry, Phytoplankton and Nutrients

Unfiltered water was analyzed for total phosphorus (TP), total Kjeldahl nitrogen (TKN), pH, and Alkalinity. Filtered water was also analyzed for total filterable phosphorus (TFP), filterable reactive phosphorus (FRP), nitrate + nitrite ($NO_3^- + NO_2^-$), ammonia (NH_4^+) and reactive silicon. Sample water was filtered through a rinsed 4.25 cm diameter Whatman GF/F cellulose fiber filter and stored frozen in phosphate free soap-washed polyethylene bottles.

TP, TFP and FRP were analyzed using a Spectronic Genesys 5 (SG5) spectrophotometer using the potassium persulfate-sulfuric acid digestion method described in Thomsen (2008). Unfiltered frozen water was sent to South Dakota University for the TKN analysis. The pH of water samples was measured with a Corning 430 meter, while alkalinity (mg L^{-1} as $CaCO_3$) was determined from 100 ml of unfiltered water titrated with 0.02 N H_2SO^4 to a pH of 4.5 and measured with a pH meter (Mettler Toledo Seven easy).

Samples for NO_3^- + NO_2^- were analyzed using the cadmium reduction method described in Thomsen (2008). NH_4^+ was analyzed with a SG5 using the phenol-sodium hypochlorite method described in Thomsen (2008). Total nitrogen, the sum of TKN and NO_3^- + NO_2^-, and the ratio of total nitrogen to TP was calculated for each sample.

For chlorophyll-*a* (chl *a*) analysis, 1.0 L of water from each sample was filtered through a Whatman GF/F filter under 15 psi vacuum pressure. Approximately 5 ml of magnesium chloride ($MgCO_3$) were added to the final 50 ml of water near the end of the filtration process to act as a preservative. Filters were stored frozen on individual petri dishes until analyzed. Filters were then ground in 90% buffered acetone using a mortar and pestle, and the resulting slurry was refrigerated in separate 15-ml glass centrifuge tubes for 4 hours to ensure maximum pigment extraction. Pigment extracts were centrifuged, decanted, and diluted to 15 ml with 90% acetone. The extracts were analyzed with a SG5 spectrophotometer using methods described in Thomsen (2008).

Reactive Silicon was determined with a SG5 spectrophotometer using the ammonium molybdate-sodium sulfite method described in Thomsen (2008). Total filterable phosphorus was determined using the same methods as those for TP utilizing filtered water. Filterable reactive phosphorus was determined using the potassium persulfate-sulfuric acid method described in Thomsen (2008).

Zooplankton

Cladocerans and copepods were identified to genus using taxonomic keys in Edmondson (1959). Zooplankton lengths were measured in triplicate 1 ml subsamples taken with a Hansen-Stempel pipette and placed in a Sedgewick-Rafter counting chamber. Lengths from a minimum of 15 animals of each species or group (typically animals are grouped at the genus level) were measured to the nearest 0.01 mm, and averaged. Biomass was estimated from species-specific linear regression equations of length and dry weight derived by Koenings et al. (1987). Zooplankton density and biomass data from the two stations were averaged for each survey.

RESULTS

SMOLT ASSESSMENT

Enumeration

The inclined plane trap was fished continuously from 16 May to 31 May, but due to extreme flooding, the trap was removed from the water from 1 June through 5 June (Table 2). The trap was reinstalled and continued to fish from 6 June through 3 July. A daily catch estimate was constructed for the five day data gap using time series analysis from the period leading up to the flood event and the period after the event. A total of 22,865 smolt were estimated to have been captured assuming the trap fished continuously from 16 May through 3 July (Table 2). Of the 22,865 smolt estimated to have been caught a total of 12,099 (53%) smolt were actually captured, counted and released and the remaining 10,766 (47%) smolt were estimated using the time series analysis (Table 2). The greatest daily sockeye salmon smolt catch was obtained a day prior to the flooding event on 31 May when 2,744 smolt were captured (Table 2; Figure 4).

Trap Efficiency and Population Estimates

Four mark-recapture experiments were conducted during the sockeye salmon smolt emigration period in 2008 (Table 2). Trap efficiencies ranged from 8.4% during the second experiment (5 --11 June) to 22.1% during the first experiment (16 – 31 May). Mean trap efficiency for the four experiments was 18.3%. The total number of sockeye salmon smolt estimated to have emigrated from Afognak Lake in 2008 was 196,941 (95% CI 148,046 – 245,835; Table 3).

Age, Weight, and Length Sampling

During the trapping period a total of 333 smolt were collected for biological sampling purposes, all of which were usable for age, weight and length data (Table 2). Summing the emigration estimates by age for all strata resulted in an emigration estimate of 92,018 age-1. (46.7%) and 104,923 age-2. (53.3%) smolt (Table 4; Figure 5). Age-1. smolt comprised 24.9% of the sample from the first stratum (16 - 31 May), the second stratum (1 - 11 June) was composed of 45.8% age-1. smolt, the third stratum (12 - 20 June) contained 86.0% age 1. fish, and the fourth stratum (21 June – 3 July) contained 100% age-1. fish.

The sampled age-1. smolt had a mean weight of 3.4 g, a mean length of 75.9 mm and a mean condition factor of 0.76 (Table 5). The sampled age-2. smolt had a mean weight of 4.0 g, a mean length of 81.7 mm, and a mean condition factor of 0.73 (Table 5).

Life History-Based Population Estimate

Using the life history-based population estimate method we projected that the 2005 escapement of 21,577 adults (brood year 2005) would produce 163,494 age-2. smolt and the 2006 escapement of 22,933 adults (brood year 2006) would produce 185,541 age-1. smolt (Table 6). Combining these two ages classes would result in theoretical emigration of 349,035 smolt from Afognak Lake in the spring of 2008 (Figure 6).

We used simple linear regression modeling to refine the 2008 emigration estimate by age. By applying the number of predicted age-1. and age-2. smolt from the 2003-2007 life history estimate models and regressing each of the age groups separately against the age-1. and age-2. smolt from the trap catch estimates resulted in stronger relationships than simply looking at the emigration as a whole. The regressed age-2. predicted estimate was 106,442 smolt (R^2=0.98, F=124, p=0.002) and the regressed age-1. estimate was 115,513 smolt (R^2=0.83, F=145, p=0.031), resulting in a combined regressed theoretical emigration of 221,956 smolt (Table 6).

LIMNOLOGICAL ASSESSMENT

Temperature, Dissolved Oxygen, Light, Water Clarity and Euphotic Volume

In 2008, water temperatures ranged from 6.9° C near the lake bottom during the spring (May-June) sampling period to 14.7° C at the surface of the lake during the summer (July-August) period. Surface and bottom temperatures remained within 2° C of each other on average throughout the sampling period indicating that mixing occurred throughout the entire water column or the thermocline was mild during the sampling periods. Dissolved oxygen concentrations ranged from 8.9 mg L^{-1} at the bottom in the summer to 12.5 mg L^{-1} at the surface in the spring.

The mean vertical extinction coefficient (Kd m^{-1}) or rate of light attenuation was -2.03 Kd m^{-1} in 2008. The mean euphotic zone depth was 9.10 m, while the Secchi disk reading was 4.4 meters. The euphotic volume for Afognak Lake in 2008 was 48.23 $10^6 m^3$.

General Water Chemistry, Phytoplankton and Nutrients

The pH averaged 6.72 with little seasonal variation (Table 7). Alkalinity levels (measured as mg L^{-1} $CaCO_3$) ranged from 9.0 to 13.3 mg L^{-1} and averaged 11.4 mg L^{-1} for the five samples collected. Seasonal chl-*a* (phytoplankton) concentrations ranged from 0.64 to 1.92 µg L^{-1} and averaged 1.22 µg L^{-1} (Table 7).

Seasonal mean TP concentrations ranged from 2.9 to 5.5 µg L^{-1} and averaged 3.8 µg L^{-1} (Table 8). Seasonal inorganic phosphorous concentrations of TFP ranged from 1.3 to 4.9 µg L^{-1} and averaged 2.3 µg L^{-1}(Table 8). The FRP concentrations ranged from 0.3 to 2.7 µg L^{-1} and averaged 1.6 µg L^{-1}.

Nitrogen levels were measured in three forms: TKN, NO_3^- + NO_2^-, and NH_{4+}. The seasonal mean TKN was 112.8 µg L^{-1}, and the greatest seasonal difference was between the May (74.0 µg L^{-1}) and September (144.0 µg L^{-1}) samples (Table 8). Seasonal NH_{4+} levels averaged 5.9 µg L^{-1} and ranged from 5.2 to 6.8 µg L^{-1}. Seasonal NO_2 + NO_3 levels averaged 65.0 µg L^{-1} and had a wide range of variability throughout the season, from 19.0 to 123.8 µg L^{-1} (Table 8). Total nitrogen concentrations ranged from 154.5 to 197.8 µg L^{-1} and averaged 177.8 µg L^{-1}. The seasonal total nitrogen to total phosphorus ratio, by weight, averaged 112.0:1 (Table 8).

Zooplankton

Zooplankton weighted mean density was 108,462 animals m^{-2} at Afognak Lake (Table 9). All zooplankton identified were crustaceans commonly referred to as either cladocerans (*Order* Anomopoda and Ctenopoda) or copepods (*Order* Calanoida, Cyclopoida, and Harpacticoida). Cladocerans were the predominant zooplankter in samples (59.6% of mean density), with the genus *Bosmina* being most abundant (53.5% of mean density). The other cladoceran genera included, *Daphnia* (2.3% of mean density), *Holopedium* (2.0% of mean density), and a group we called "other cladocerans," which consisted of various unidentified immature cladocera (1.8% of mean density). Of the copepods (40.4% of mean density), the most abundant group consisted of what we called "other copepods" (19.7% of the mean density), which was made up mostly of the genus *Harpaticus* and various unidentified nauplii (larvae), followed in abundance by the genus *Epischura* (17.2% of the mean density). The copepod genus *Cyclops*, considered an important member of the zooplankton community in sockeye salmon lakes, were not very abundant (2.4% of mean density). The genus *Diaptomus* made up the smallest portion of the copepods at 1.1% of the mean density.

Zooplankton mean biomass was 110.9 mg m^{-2} (Table 9). Despite only making up 40.4% of the mean density, the copepods composed 50.5% of the zooplankton mean biomass due to their larger size. The copepod genus *Epischura* represented the greatest percentage of biomass (43.2%), closely followed by the cladoceran genus *Bosmina* (42.0%). The remaining biomass was mostly comprised of *Diaptomus* (4.4%) and *Daphnia* (3.9%) *Holopedium* (3.7%) and *Cyclops* (2.8%). "Other copepods" consisted of larvae that were too small to measure and could not be included in the biomass estimate.

The copepod *Diaptomus* was the largest zooplankton, having a mean length of 0.94 mm (Table 9). Of the remaining copepods, *Epischura* had a mean length of 0.83 mm, and *Cyclops* had a mean length of 0.60 mm. *Daphnia*, the largest cladoceran, had a mean length of 0.65 mm followed by *Holopedium* (0.47 mm) and *Bosmina* (0.30 mm).

DISCUSSION

SMOLT ASSESSMENT

This was the sixth consecutive year of the Afognak Lake smolt assessment study in which the same methods and materials were used. The data collected from the prior years indicated that average trap efficiencies were consistent from year to year, despite the fact that seasonal conditions, water levels, and field personnel operating the system varied annually. The annual mean trap efficiencies for the preceding five-year study were within a 5% range (2003: 19.9% 2004: 18.6%; 2005: 14.9%; 2006: 19.5%; 2007: 19.9%; Appendix 1). These results suggest that reliable and comparable estimates of annual smolt production have been made each year of the study.

In 2008, the total trap efficiency (18.0%) was also within the range of prior years but due to a high water flood event the trap was prevented from fishing during the middle of the study. The average precipitation during the month of May is 14.3 cm while in 2008 more than 35 cm of rainfall was recorded by the National Climate Data Center at the Kodiak airport. Despite exhaustive attempts to maintain uninterrupted catch operations, the trap broke apart and was not reinstalled until the waters subsided five days later. This five day period coincided with the peak historical timing of the emigration (Appendix 2). In the days leading up to the flood event the river level substantially increased and at the same time the daily catch of smolt sharply increased until the trap failed on 1 June. The combination of high water and historical emigration timing strongly indicate that a large portion of the emigration left the freshwater environment during this period. Using the data collected pre- and post-flood we applied time series analysis to replicate the theoretical trap catch during the period of no trapping. Although we feel this is a statistically valid approach of obtaining a catch estimate and resulting population estimate it should be cautiously viewed and considered with less confidence than prior year estimates.

We also employed an alternative and distinctly different method of estimating the annual smolt population using the life history based model. Using escapement and fecundity data and biological assumptions for egg-to-smolt survival rates we were able to calculate a theoretical estimate of total number of smolt as previously reported. The 2008 life history estimate of 349,035 smolt was much greater than the trap catch estimate of 196,941 smolt. Through regression analysis we estimate a total of 221,956 smolt estimated to have migrate out in 2008. The regressed life history model still predicted more fish to have migrated out than the time series trap estimate, but it also supports and points to a lower emigration than has historically been observed. Despite the supporting evidence of a low emigration we still cautiously consider the data. The uncertainty associated with the accuracy of the trap estimate is due in most part to the timing of the flooding event. This event not only occurred during the historical peak of the emigration but also when the emigration of age-2. fish historically transition over to a dominance of age-1. smolt, further complicating the ability to accurately estimate the population and age relationship. Emigration data obtained from subsequent years will enable us to strengthen these emigration models and further corroborate age composition estimates.

Slightly more than half of the 2008 emigration was composed of age-2. smolt (53.3%) while the age-1. smolt made up the remaining (46.7%) portion of the emigration. The dominance of age-2. smolt is a deviation from recent data (2003-2007) in which age-1. smolt on average composed 81.8% of the out emigration (Figure 7). Systems producing large proportions of age-1. smolt may have favorable freshwater rearing conditions. An increased proportion of older smolt may indicate decreased food availability due to either declining lake productivity or increasing numbers of juvenile salmon (Barnaby 1944; Burgner 1964; Foerster 1968; Krokhin 1957; Koenings et al. 1993). When the juvenile population begins to exceed the rearing capacity of a system, a greater proportion of the population may spend two or more years in freshwater before growing large enough to transform into smolt (Honnold and Schrof 2004). Based on the average dominance (81.8%) of age-1. smolt emigrating from Afognak Lake in recent years, the freshwater rearing capacity has not appeared to have been exceeded and has been sufficient to support the juvenile population produced from recent escapements. The switch in the 2008 age composition may be due to rearing limitations but at the same time it may be a function of the inability to capture smolt during the peak of the emigration resulting in compromised data sets. Other environmental factors, such as climate change, may also be at play and will continue to be examined.

Mean size and condition of age-1. smolt sampled in 2008 (n=169; 3.4 g, 75.9 mm, K=0.76) indicated a drop in weight and condition factor in comparison to recent year (2003-2007) averages of age-1. smolt (n=5,374; 3.5 g, 74.6 mm, K=0.81; Appendix 3). In 2007 and 2008 air temperatures recorded by the by the National Climate Data Center at the Kodiak airport averaged 1.2°C less than the 76-year annual average (1931-2006). Water temperature is the single most important factor in fish development as metabolic rates increase as temperatures increase (Piper et al. 1982). The rate of egg and alevin development and emergence is greatly dependent upon the temperature regimes they experience while in the redd (Groot and Margolis 1991, page 28). The late-winter and early-spring temperatures in 2007 and 2008 averaged 1.8°C less than the 76 year historical average for the same 5 month time period. Most likely these cooler temperatures not only resulted in fry emerging later and impeded metabolic processes but also delayed the development of phytoplankton resulting in later growth and development of zooplankton and possibly causing zooplankton to go into diapause thus greatly reducing the forage base for juveniles.

The start of the emigration in 2007 and 2008 was later than the timing observed from 2003 to 2006 (Baer, et al. 2009; Appendix 4). Smolt emigration typically begins in mid-May, peaks early to mid-June, and ends by early July. Smolt emigration in 2007 and 2008 did not begin until the end of May but, as in prior years, it peaked in mid-June and ended in early July. Observations from other systems (Barnaby 1944; Burgner 1962; Krogius and Krokhin 1948) indicated that older and larger smolt tend to migrate earlier. The delayed emigration, smaller smolt size, and transition to a dominance of age-2. smolt in 2008 corroborates the theory that colder spring conditions are driving freshwater productivity.

LIMNOLOGICAL ASSESSMENT

Most of the seasonal mean measurements of lake physical properties in 2008 were consistent with those from past years. Water temperatures were the exception in 2007 and 2008 with colder than the seasonal average (1989 to 2006) readings (Appendix 5). With a mean depth of 8.6 m and a maximum depth of 23.0 m, Afognak Lake is considered a shallow lake that is easily influenced and mixed by wind and ice melt (Cole 1983). As a result of these mixing events, Afognak Lake is typically stratified into warm epilimnion and cool hypolimnion layers for only short periods of time each year. High dissolved oxygen levels recorded in 2008 were consistent with historical averages (Appendix 6). Light, euphotic volume and euphotic zone data recorded in 2008 were also similar to historical average values (1990-2007; Appendix 7).

Historical nutrient and algal pigment concentrations have exhibited high levels of annual variation and irregular fluctuations, although notable differences were discernable between the eleven-year period in which the lake was fertilized (1990-2000) and the last eight years when the lake was not artificially fertilized (2001-2008; Appendix 8). The average TP, TKN, and NH_{4+} concentrations were higher during the fertilization years as compared to the non-fertilization years. During 2008, some surface water nutrient concentrations (TP: 3.8 μg L^{-1} and TKN: 113 μg L^{-1}) were lower than the overall average concentration during the previous seven-year (2001-2007) post-fertilization period (TP: 7.0 μg L^{-1} and TKN: 131 μg L^{-1}), while the $NO_3^- + NO_2^-$ (65 μg L^{-1}) concentrations in 2008 were higher than the post fertilization year averages (43 μg L^{-1}).

Seasonal average algal standing crop in 2008, as measured by chl-*a* concentration (1.22 μg L^{-1}) was less than the average concentration during the previous seven-year post-fertilization period (1.58 μg L^{-1}) as well as during the fertilization period (1.54 μg L^{-1}).

Seasonal mean water chemistry has not varied a great deal, although average pH and alkalinity were both lower during the fertilization period (pH: 6.8; alkalinity: 9.5) than during the post-fertilization period (pH: 6.9; alkalinity: 10.3; Appendix 9). During 2008, average pH (6.7) was less than the overall average for the fertilization period and the previous seven-year post-fertilization period. Average alkalinity for 2008 (11.4 mg L^{-1}) was greater than the overall averages for the fertilization and previous six-year post-fertilization periods.

During 2008, seasonal mean zooplankton density (76,222 individuals m^{-2}) and biomass (103 mg m^{-2}) estimates at station 2 were much less than estimates from station 1 (94,126 individuals m^{-2} and 119 mg m^{-2}; Appendix 10). The reduced density and biomass reported at station 2 as compared to station 1 has been a common theme and is likely due to station 2 being closer to the lake outlet. Lake water residence time is estimated to be only 0.4 years for Afognak Lake, so rapid lake flushing may remove zooplankton quicker than they can be replenished through reproduction (Schrof and Honnold 2005; White et al. 1990). Rapid flushing may have also affected nutrient availability for phytoplankton, which could affect zooplankton production. This effect may be further compounded in times, such as the springs of 2007 and 2008, when there is more precipitation than normal.

Since the zooplankton community serves as the primary forage base in lakes for juvenile sockeye salmon, total zooplankton density and biomass are often used as a measure to assess juvenile sockeye salmon production potential (Koenings et al. 1987). During 2008, Station 1 weighted mean total zooplankton density (94,126 individuals m^{-2}) and biomass (119 mg m^{-2}) levels were less than estimates for the pre-fertilization period (1987-1989: 134,747 no. m^{-2} and 194 mg m^{-2}) and the previous seven-year post-fertilization period (2001-2007: 107,550 individuals and 136 mg m^{-2}; Appendix 10).

Since juvenile sockeye salmon prefer cladocerans rather than copepods, cladoceran abundance is viewed as a better indicator of potential juvenile sockeye salmon production (Koenings et al. 1987; Kyle 1996). The 2008 abundance of the cladoceran *Daphnia* at station 1 (4,231 individuals m^{-2} and 7 mg m^{-2}) was much greater than its overall average abundance during the pre-fertilization period (1,986 individuals and 3 mg m^{-2}) and slightly less than the previous six-year post-fertilization period (4,832 individuals and 6 mg m^{-2}; Appendix 10). The presence and abundance of *Daphnia*, a primary prey item for juvenile sockeye salmon, is considered an important indicator of lake forage activity (Honnold and Schrof 2001; Kyle 1996). Similar to *Daphnia,* the cladoceran *Holopedium* had a density (3,079 individuals m^{-2}) and biomass (6 mg m^{-2}) in 2008 that was much greater than the pre-fertilization years (1,716 individuals m^{-2} and 4 mg m^{-2}) and the post-fertilization years (2,466 individuals m^{-2} and 4 mg m^{-2} Appendix 10). The abundance and the biomass of the cladoceran *Bosmina* (66,762 individuals m^{-2} and 55 mg m^{-2}) in 2008 was less than the average from the pre-fertilization years (104,823 individuals m^{-2} and 99 mg m^{-2}) and the post-fertilization years (67,559 individuals m^{-2} and 57 mg m^{-2}). Despite *Bosmina* comprising the vast majority of the cladocerans (81% of total Cladoceran biomass) they may not be a good indicator of available forage. Being about half the size of *Daphnia* and about two-thirds the size of *Holopedium, Bosmina* (0.30 mm) are a more difficult prey item for juvenile salmon to locate and eat due to their small size (Koenings and Kyle 1997).

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TABLES AND FIGURES

Table 1.–Afognak Lake sockeye salmon escapement, harvest, and total run estimates, 1978-2008.

		Harvest				
Year	Escapement	Commercial[a]	Subsistence[b]	Sport[c]	Total	Total Run
1978	52,701	3,414	1,632	524	5,570	58,271
1979	82,703	2,146	2,069	524	4,739	87,442
1980	93,861	28	3,352	524	3,904	97,765
1981	57,267	16,990	3,648	524	21,162	78,429
1982	123,055	21,622	3,883	524	26,029	149,084
1983	40,049	4,349	3,425	524	8,298	48,347
1984	94,463	6,130	3,121	524	9,775	104,238
1985	53,563	1,980	6,804	524	9,308	62,871
1986	48,328	2,585	3,450	524	6,559	54,887
1987	25,994	1,323	2,767	524	4,614	30,608
1988	39,012	14	2,350	524	2,888	41,900
1989	88,825	0	3,859	524	4,383	93,208
1990	90,666	22,149	4,469	524	27,142	117,808
1991	88,557	47,237	5,899	524	53,660	142,217
1992	77,260	2,196	4,638	600	7,434	84,694
1993	71,460	1,848	4,580	524	6,952	78,412
1994	80,570	17,362	3,329	524	21,215	101,785
1995	100,131	67,665	4,390	524	72,579	172,710
1996	101,718	106,141	11,023	258	117,422	219,140
1997	132,050	10,409	12,412	535	23,356	155,406
1998	66,869	26,060	4,690	718	31,468	98,337
1999	95,361	34,420	5,628	237	40,285	135,646
2000	54,064	14,124	7,572	364	22,060	76,124
2001	24,271	0	4,720	169	4,889	29,160
2002	19,520	0	1,279	41	1,320	20,840
2003	27,766	0	604	0	604	28,370
2004	15,181	0	567	10	577	15,758
2005	21,577	356	696	134	1,186	22,763
2006	22,933	6	451	36	493	23,426
2007	21,070	0	490	–[d]	490	21,560
2008	26,874	0	515	–[d]	–[d]	27,389

[a] Statistical fishing section 252-34 (Southeast Afognak District).

[b] Data from ADF&G subsistence catch database 1978-2008.

[c] Data from ADF&G Sport Fish Division statewide harvest survey (SWHS) for 1992, 1996-2008; SWHS data for other years did not have enough respondents to provide reliable estimates. Four years with reliable data were averaged and entered for years with no data.

[d] Not available at time of publication

Table 2.–Sockeye salmon smolt counts, number of samples collected, mark-recapture counts, and trap efficiency ratios from trapping at Afognak River, 2008.

Date	Catch daily	Catch cumulative	Dye test period cumulative	AWL sample cumulative	Number marked releases[a]	Marked recoveries cumulative	Trap efficiency (%)
16-May	0	0					
17-May	0	0					
18-May	0	0					
19-May	0	0					
20-May	3	3					
21-May	6	9					
22-May	3	12					
23-May	8	20					
24-May	14	34					
25-May	18	52					
26-May	61	113		40			
27-May	97	210					
28-May	936	1,146		60			
29-May	1,319	2,465		85	202	17	
30-May	1,307	3,772		108		35	
31-May	2,744	6,516	15,471	163		44	22.1%
1-Jun	2,525 [b]	9,041					
2-Jun	2,324 [b]	11,365					
3-Jun	2,138 [b]	13,503					
4-Jun	1,968 [b]	15,471					
5-Jun	1,811 [b]	17,282					
6-Jun	265	17,547		203			
7-Jun	464	18,011		223			
8-Jun	222	18,233		243	394	24	
9-Jun	279	18,512		263		32	
10-Jun	104	18,616				0	
11-Jun	400	19,016	3,545	268		0	8.4%

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Table 2.–Page 2 of 2.

Date	Catch daily	Catch cumulative	Dye test period cumulative	AWL sample cumulative	Number marked releases[a]	Marked recoveries cumulative	Trap efficiency (%)
12-Jun	762	19,778					
13-Jun	570	20,348		288	244	33	
14-Jun	182	20,530				44	
15-Jun	190	20,720		298		52	
16-Jun	168	20,888				53	
17-Jun	278	21,166		318		0	
18-Jun	270	21,436				0	
19-Jun	139	21,575				0	
20-Jun	80	21,655	1,877		0	0	22.0%
21-Jun	147	21,802					
22-Jun	29	21,831					
23-Jun	56	21,887					
24-Jun	48	21,935					
25-Jun	60	21,995					
26-Jun	196	22,191					
27-Jun	197	22,388		323	306	0	
28-Jun	181	22,569		333		57	
29-Jun	121	22,690				62	
30-Jun	110	22,800				0	
1-Jul	39	22,839				0	
2-Jul	17	22,856				0	
3-Jul	9	22,865	1,290			0	20.5%
Trap Pulled					Average Trap Efficiency=		18.3%

[a] Adjusted number released using the delayed mortality formulation.

[b] Trap was not fishing due to flooding as a result estimates were derived from time series analysis.

Table 3.–Population estimate of the sockeye salmon smolt emigration from Afognak Lake, 2008.

Stratum (h)	Beginning Date	Ending Date	uh Unmarked	Mh Released	mh Recovered	Uh Estimate	var(Uh) Variance	95% Confidence Interval lower	upper
1	5/16	5/31	6,516	202	44	29,434	1.48E+07	21,903	36,966
2	6/1	6/11	12,500	394	32	149,621	6.05E+08	101,411	197,831
3	6/12	6/20	2,639	244	53	11,989	2.08E+06	9,162	14,815
4	6/21	7/3	1,210	306	62	5,896	4.54E+05	4,575	7,217
Total						**196,941**	6.22E+08	**148,046**	**245,835**
						SE=	24,946		

Table 4.–The Afognak Lake sockeye salmon smolt emigration estimates based on percents by age class and dye test period, 2008.

Stratum		Age 1.	Age 2.	Age 3.	Total
1	Number	7,344	22,091	0	29,434
(5/16-5/31)	Percent	24.9%	75.1%	0.0%	100.0%
2	Number	68,464	81,157	0	149,621
(6/1-6/11)	Percent	45.8%	54.2%	0.0%	100.0%
3	Number	10,314	1,675	0	11,989
(6/12-6/20)	Percent	86.0%	14.0%	0.0%	100.0%
4	Number	5,896	0	0	5,896
(6/21-7/3)	Percent	100.0%	0.0%	0.0%	100.0%
Total	Number	92,018	104,923	0	196,941
	Percent	46.7%	53.3%	0.0%	100.0%

Table 5.–Length, weight, and condition of sockeye salmon smolt from the Afognak River, 2008.

Stratum	Dates	Sample Size	Weight (mm) Mean	Weight (mm) Standard Error	Length (g) Mean	Length (g) Standard Error	Condition Mean	Condition Standard Error
Age 1.								
1	5/16-5/31	33	3.0	0.06	74.1	0.55	0.74	0.010
2	6/1-6/11	77	3.2	0.05	75.4	0.41	0.75	0.005
3	6/12-6/19	44	3.5	0.09	76.1	0.54	0.78	0.006
4	6/20-7/3	15	4.6	0.12	81.6	0.47	0.84	0.018
Totals		169	3.4	0.05	75.9	0.30	0.76	0.004
Age 2.								
1	5/16-5/31	130	4.0	0.04	81.4	0.24	0.73	0.004
2	6/1-6/11	28	4.1	0.07	81.8	0.44	0.75	0.010
3	6/12-6/19	6	5.0	0.46	86.5	2.17	0.77	0.026
4	6/20-7/3	0						
Totals		164	4.0	0.04	81.7	0.23	0.73	0.003

Table 6.–Afognak Lake sockeye salmon theoretical production of eggs, emergent fry, and smolt by age from brood years 2005 and 2006 and predicted smolt emigration in 2008.

Production		Brood Year		Estimate 2008
Parameter	Assumption	2005	2006	Age-1. and -2. smolt
Escapement		21,577	22,933	
Females spawning	1:1 sex ratio	10,789	11,467	
Deposited Eggs	2,195 (2005) 2,077 (2006) per female [a]	23,680,758	23,815,921	
Emergent Fry	7% egg-to-fry survival[b]	1,657,653	1,667,114	
Smolt	21% fry-to-smolt survival[c]	348,107	350,094	
2008 Smolt Emigration	46.7% age-1., 53.3% age-2.[d]	185,541	163,494	349,035
2008 Smolt Emigration (Regressed Estimate)		115,513	106,442	221,956

[a] Actual fecundity as reported from Pillar Creek Hatchery (2005 and 2006).
[b] Egg to fry survival assumption from Drucker (1970), Bradford (1995) and Koenings and Kyle (1997).
[c] Fry to smolt survival assumptions from Koenings and Kyle (1997).
[d] Age composition assumptions derived from 2008 smolt age class estimates listed in Table 4.

Table 7.–General water chemistry and algal pigment concentrations at 1-m water depth, station 1, Afognak Lake 2008.

Date	pH (units)	Alkalinity (mg L^{-1})	Silicon (μg L^{-1})	Chlorophyll *a* (μg L^{-1})
21-May	6.60	13.3	ND	0.64
17-Jun	6.50	9.0	ND	0.64
15-Jul	6.89	10.3	ND	1.92
20-Aug	6.79	11.8	ND	1.92
22-Sep	6.84	12.5	ND	0.96
Average	6.72	11.4	ND	1.22
SD	0.17	1.7	ND	0.66

Table 8.–Seasonal phosphorus and nitrogen concentrations at 1 m water depth, station 1, Afognak Lake, 2008.

Date	Total filterable-P ($\mu g\ L^{-1}$)	Filterable reactive-P ($\mu g\ L^{-1}$)	Total-P ($\mu g\ L^{-1}$)	Ammonia ($\mu g\ L^{-1}$)	Total Kjeldahl Nitrogen ($\mu g\ L^{-1}$)	Nitrate + Nitrite ($\mu g\ L^{-1}$)	Total Nitrogen ($\mu g\ L^{-1}$)	TN:TP ratio
21-May	4.9	0.3	3.0	5.8	74.0	123.8	197.8	146.0
17-Jun	1.6	1.5	2.9	5.2	104.0	91.8	195.8	149.5
15-Jul	1.3	2.7	3.2	5.6	104.0	50.5	154.5	106.9
20-Aug	2.0	1.5	5.5	5.9	138.0	19.0	157.0	63.2
22-Sep	1.9	1.9	4.3	6.8	144.0	39.7	183.7	94.6
Average	2.3	1.6	3.8	5.9	112.8	65.0	177.8	112.0
SD	1.5	0.9	1.1	0.6	28.6	42.3	20.8	36.3

Table 9.–Weighted mean zooplankton density, biomass, and size by station from Afognak Lake, 2008.

Station	*n*		*Epischura*	*Diaptomus*	*Cyclops*	Other Copepods	*Bosmina*	*Daphnia*	*Holopedium*	Other Cladocerans	Total Copepods	Total Cladocerans	Total all zooplankton
1	5	density (no. m^{-2})	16,561	823	2,670	23,061	66,762	4,231	3,079	2,548	43,115	76,620	119,735
		%	13.8%	0.7%	2.2%	19.3%	55.8%	3.5%	2.6%	2.1%	36.0%	64.0%	100.0%
		biomass (mg m^{-2})	44.9	2.1	3.4	–[a]	55.1	7.0	6.1	–[a]	50.4	68.3	118.6
		%	37.9%	1.7%	2.9%	–[a]	46.5%	5.9%	5.2%	–[a]	59.8%	40.2%	100.0%
		size (mm)	0.84	0.83	0.61	–[a]	0.30	0.62	0.49	–[a]			
2	5	density (no. m^{-2})	20,786	1,592	2,484	19,693	49,260	786	1,314	1,274	44,555	52,634	97,189
		%	21.4%	1.6%	2.6%	20.3%	50.7%	0.8%	1.4%	1.3%	37.2%	44.0%	81.2%
		biomass (mg m^{-2})	51.0	7.7	2.8	–[a]	37.9	1.6	2.1	–[a]	61.5	41.6	103.1
		%	49.4%	7.5%	2.8%	–[a]	36.7%	1.6%	2.0%	–[a]	59.7%	40.3%	100.0%
		size (mm)	0.81	1.04	0.59	–[a]	0.29	0.67	0.44	–[a]			
1 & 2 Averaged		density (no. m^{-2})	18,674	1,208	2,577	21,377	58,011	2,509	2,197	1,911	43,835	64,627	108,462
		%	17.2%	1.1%	2.4%	19.7%	53.5%	2.3%	2.0%	1.8%	40.4%	59.6%	100.0%
		biomass (mg m^{-2})	48.0	4.9	3.1	–[a]	46.5	4.3	4.1	–[a]	56.0	54.9	110.9
		%	43.2%	4.4%	2.8%	–[a]	42.0%	3.9%	3.7%	–[a]	50.5%	49.5%	100.0%
		size (mm)	0.83	0.94	0.60	–[a]	0.30	0.65	0.47	–[a]			

[a] Other copepods and cladocerans are composed of immature species that are too small to measure to generate a biomass estimate.

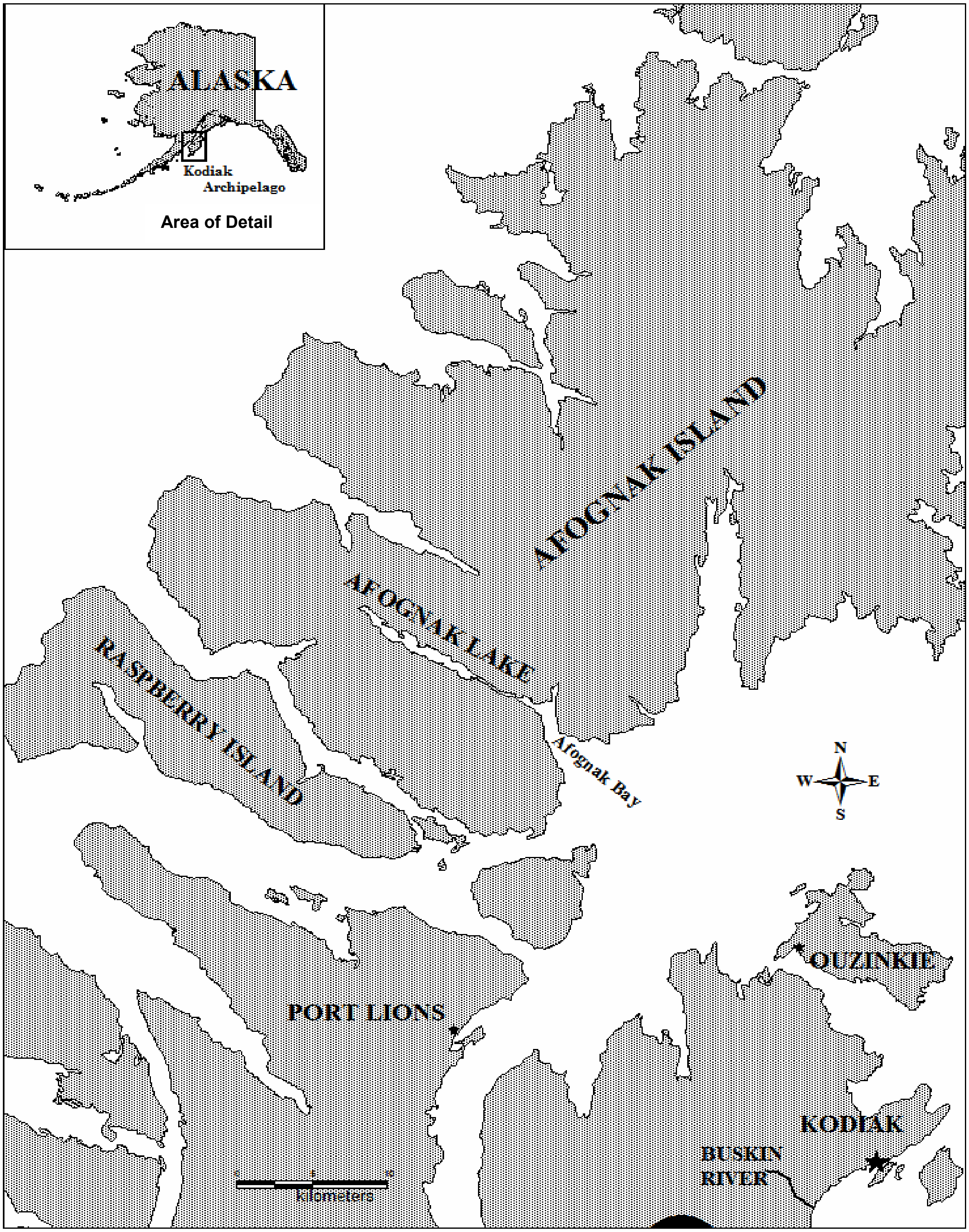

Figure 1.–This map displays the location of Kodiak City, and the villages of Port Lions, and Ouzinkie and their proximity to the Afognak Lake drainage on Afognak Island.

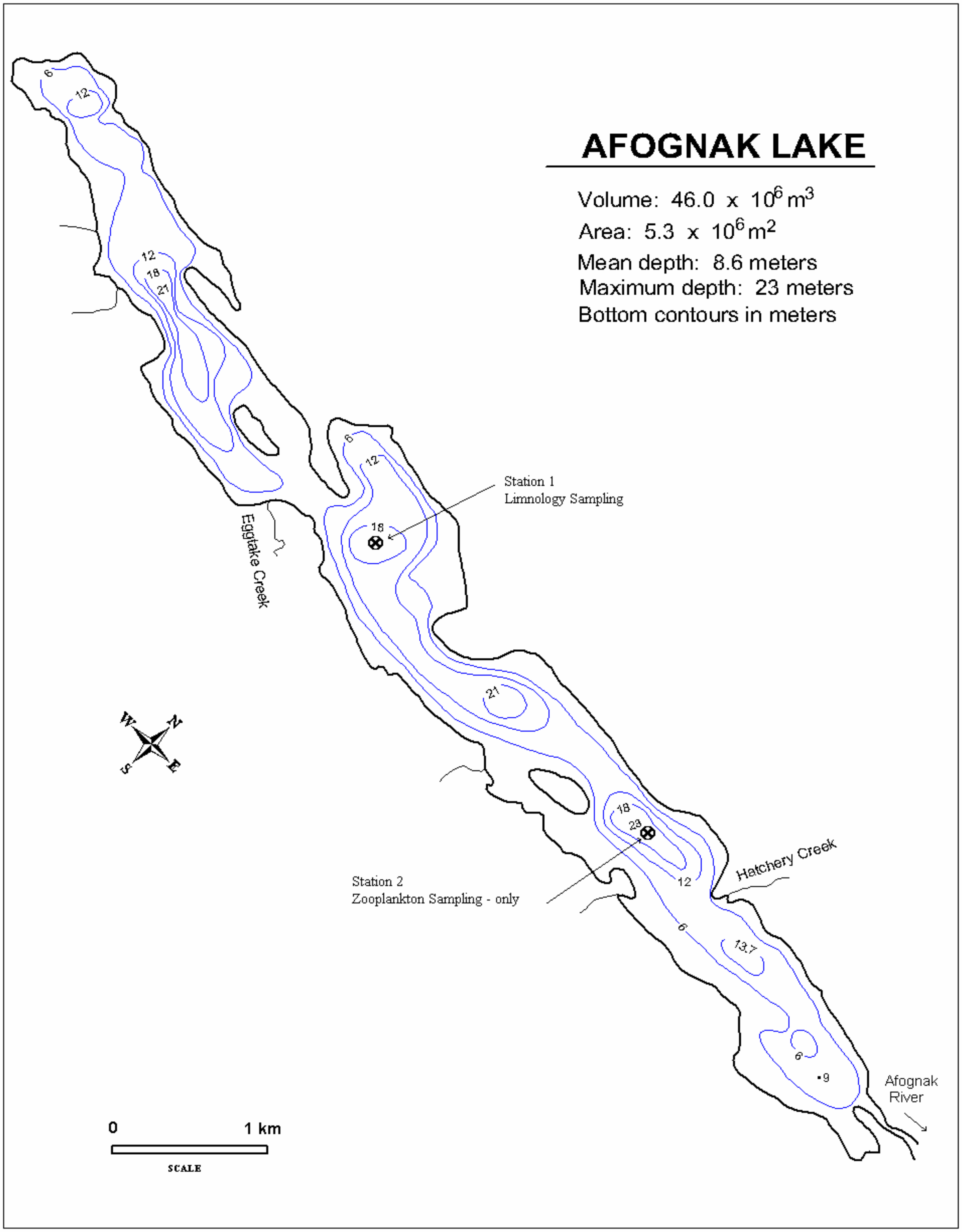

Figure 2.–Bathymetric map showing the limnology and zooplankton stations on Afognak Lake.

Figure 3.–The smolt trapping system set up in the Afognak River, 2008.

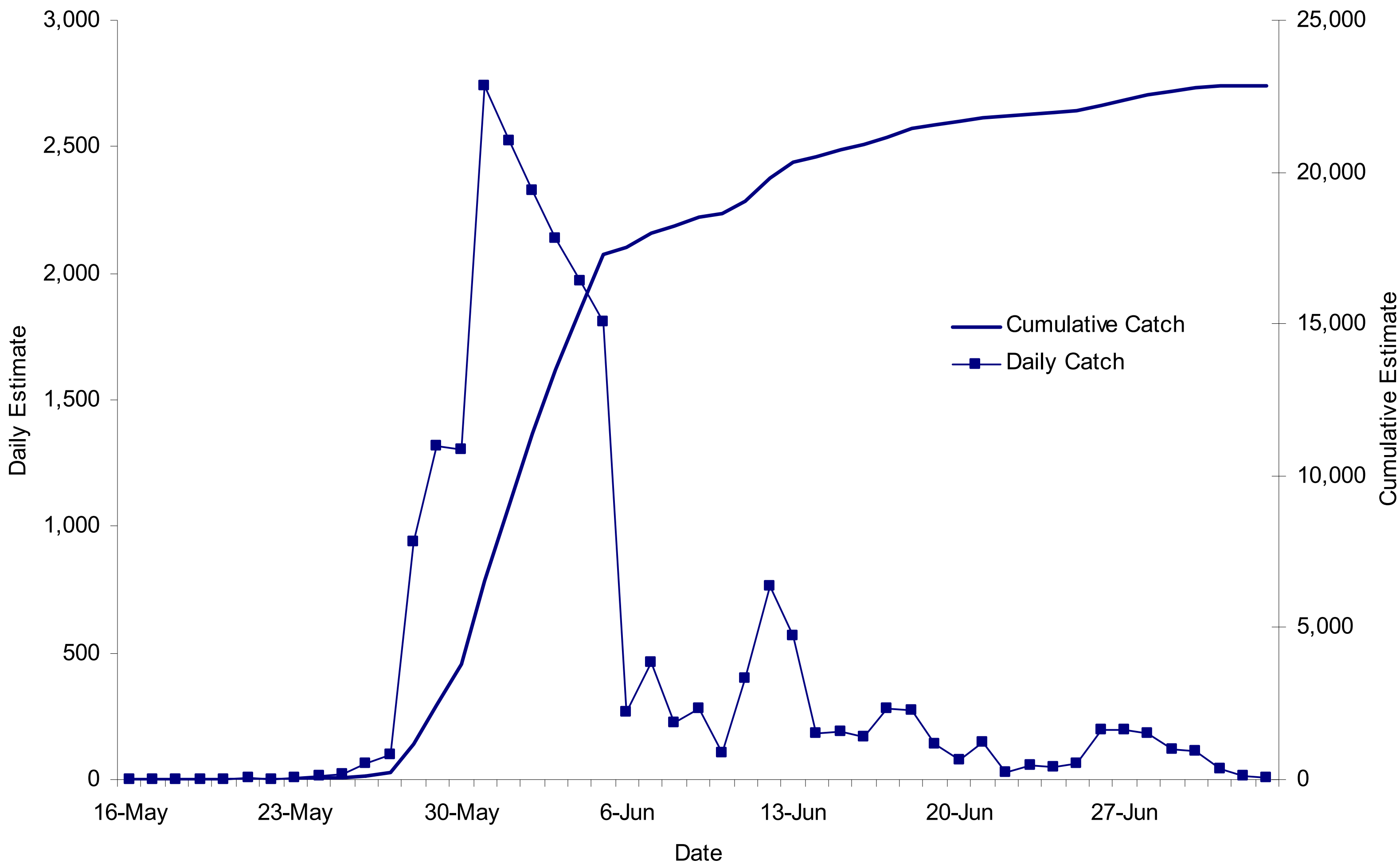

Figure 4.–Daily and cumulative sockeye salmon smolt trap catch estimates from 16 May to 3 July in the Afognak River, 2008.

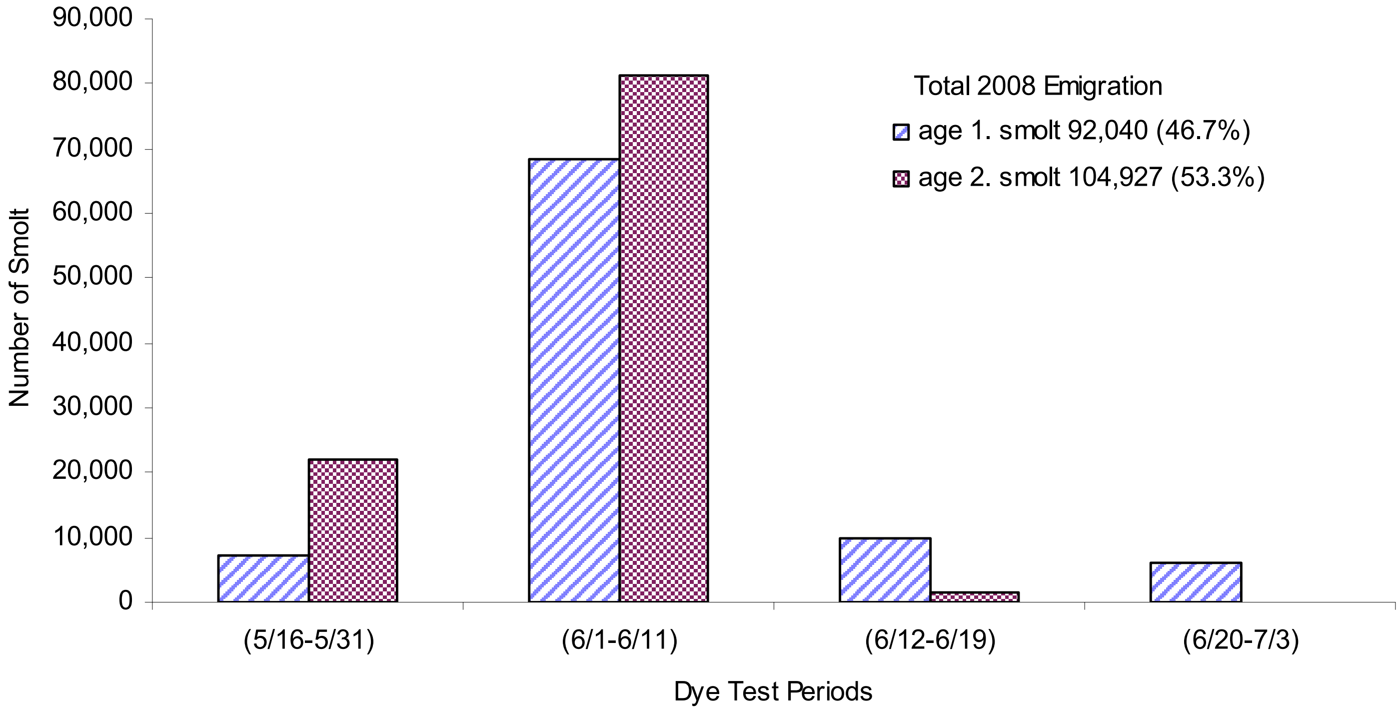

Figure 5.–Afognak Lake sockeye salmon smolt emigration by age class and dye test period, 2008.

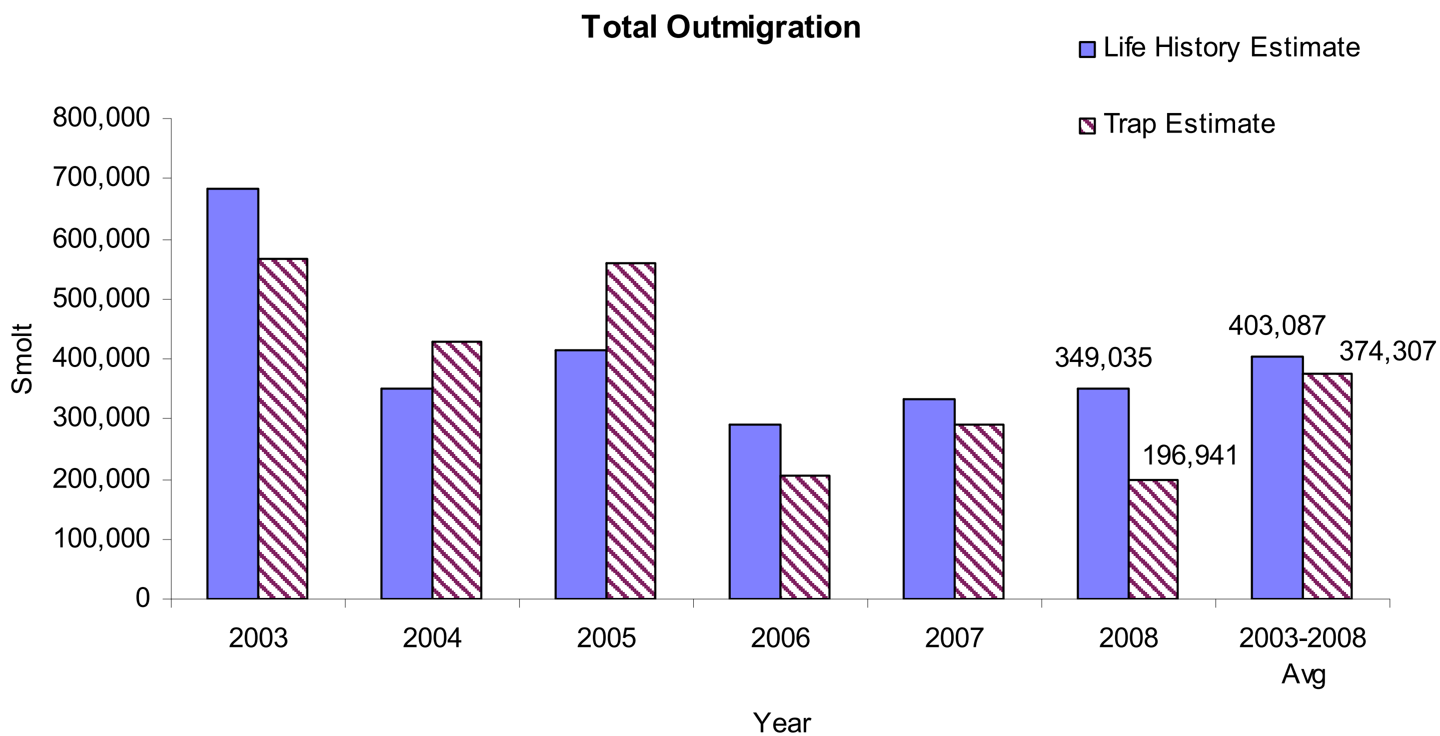

Figure 6.–Afognak Lake emigration estimates from trap catches and theoretical emigration estimates based on brood year escapements, 2003-2008.

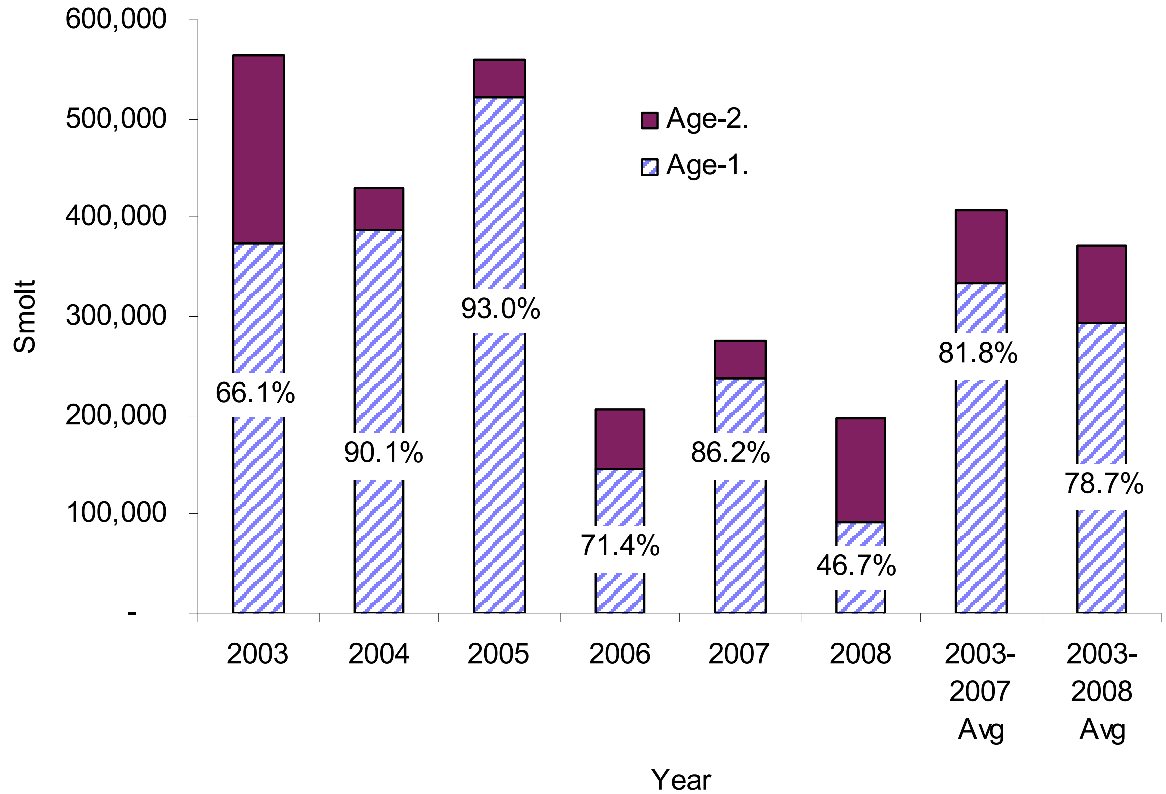

Figure 7.–Sockeye salmon smolt emigration by age from Afognak Lake, 2003-2008.

APPENDIX: SUPPORTING HISTORICAL INFORMATION

Appendix 1.–Population estimates of the sockeye salmon emigrations from Afognak Lake 2003-2008.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg. trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	upper
2003										
1	5/12	5/19	1,387	239	5	2.1%	55,480	4.31E+08	14,809	96,151
2	5/20	5/25	2,912	239	5	2.1%	116,480	1.89E+09	31,188	201,772
3	5/26	5/31	11,966	706	161	22.8%	52,222	1.31E+07	45,136	59,308
4	6/1	6/7	31,358	638	133	20.8%	149,536	1.31E+08	127,063	172,008
5	6/8	6/10	11,153	686	257	37.5%	29,698	2.18E+06	26,807	32,589
6	6/11	6/18	18,696	679	103	15.2%	122,243	1.21E+08	100,663	143,823
7	6/19	6/26	4,762	506	79	15.6%	30,179	9.63E+06	24,097	36,261
8	6/27	7/3	736	218	17	7.8%	8,955	3.97E+06	5,050	12,859
Total			82,970	3,911	760	19.9%	564,793	2.61E+09	374,814	754,772
							SE=	51,047		
2004										
1	5/11	5/26	24,278	525	56	10.7%	224,039	7.73E+08	169,530	278,548
2	5/27	6/3	17,727	547	96	17.6%	100,148	8.47E+07	82,111	118,186
3	6/4	6/11	16,658	700	211	30.1%	55,081	1.01E+07	48,864	61,299
4	6/12	6/19	5,086	613	119	19.4%	26,023	4.61E+06	21,815	30,231
5	6/20	7/3	3,779	581	88	15.1%	24,712	5.88E+06	19,958	29,466
Total			67,528	2,966	570	18.6%	430,004	8.79E+08	371,905	488,104
							SE=	2.96E+04		

-continued-

Appendix 1.–Page 2 of 3.

Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg. trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	upper
					2005					
1	5/10	5/21	27,226	489	70	14.3%	184,879	4.05E+08	145,443	224,314
2	5/22	5/26	13,627	518	43	8.3%	155,259	4.89E+08	111,932	198,587
3	5/27	6/5	15,210	482	44	9.1%	158,499	4.94E+08	114,948	202,050
4	6/6	6/27	17,634	368	103	28.0%	61,593	2.58E+07	51,640	71,546
Total			73,697	1,857	260	14.9%	560,230	1.41E+09	486,554	633,906
							SE=	3.76E+04		
					2006					
1	5/16	6/1	25,983	312	73	23.6%	110,017	1.24E+08	88,224	131,809
2	6/2	6/6	8,199	515	98	19.2%	42,726	1.49E+07	35,153	50,299
3	6/7	6/16	7,108	485	95	19.8%	35,975	1.09E+07	29,519	42,432
4	6/17	6/29	2,534	492	75	15.4%	16,435	3.06E+06	13,009	19,861
Total			43,824	1,804	341	19.5%	205,153	1.52E+08	180,952	229,353
							SE=	1.23E+04		
					2007					
1	5/10	6/5	14,450	415	51	12.5%	115,690	2.22E+08	86,501	144,879
2	6/6	6/12	19,469	202	124	61.5%	31,680	3.09E+06	28,235	35,125
3	6/13	6/20	15,281	510	82	16.2%	94,135	8.88E+07	75,660	112,609
4	6/21	6/27	5,216	541	108	20.1%	25,914	4.98E+06	21,541	30,288
5	6/28	7/4	899	401	44	11.2%	8,031	1.31E+06	5,790	10,272
Total			55,315	2,070	409	19.9%	275,450	3.20E+08	240,388	310,512
							SE=	1.79E+04		

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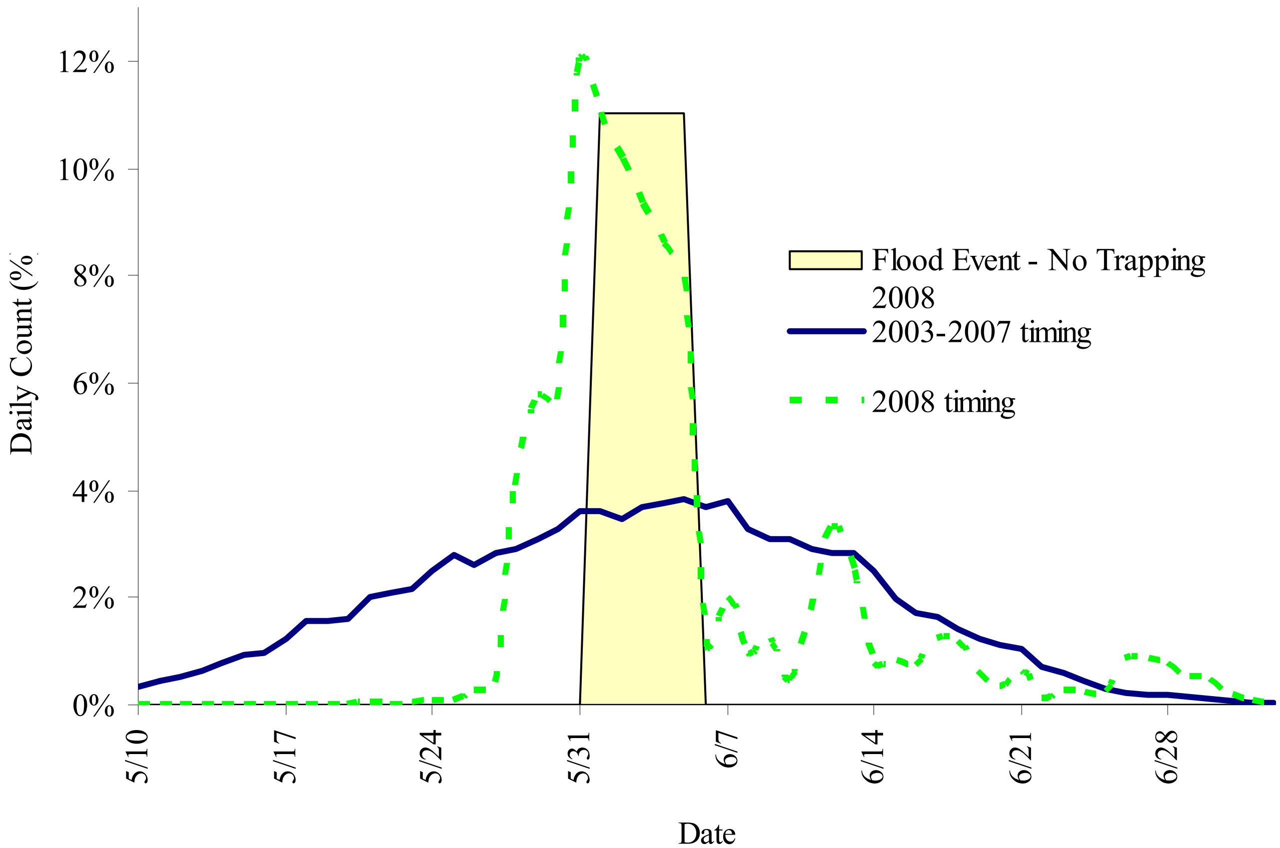
Appendix 1.–Page 3 of 3.

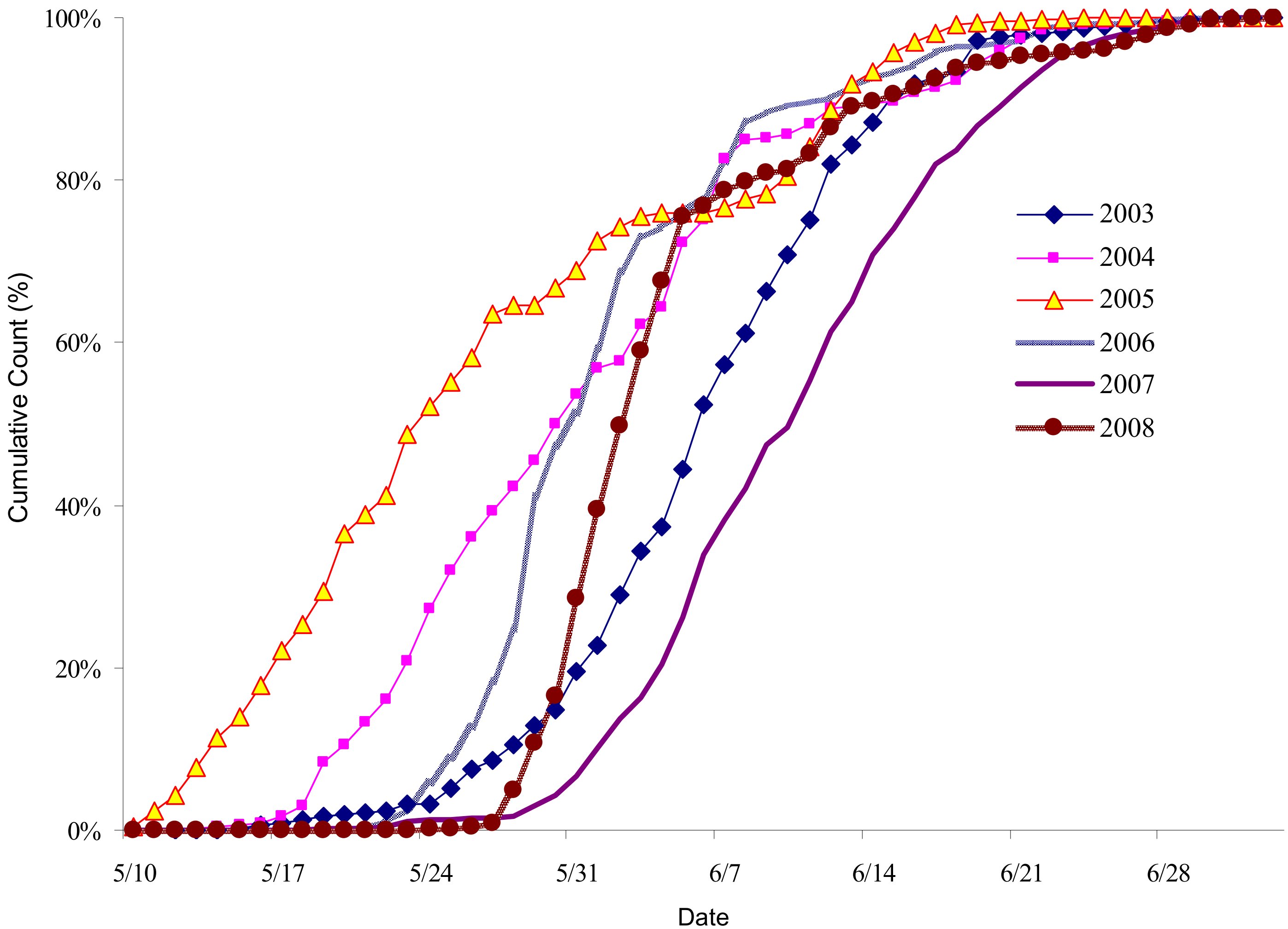
Stratum (h)	Starting date	Ending date	Catch (u_h)	Released (M_h)	Recaptured (m_h)	Avg. trap efficency (%)	Estimate (U_h)	Variance (U_h)	95% Confidence Interval lower	upper
						2008				
1	5/16	5/31	6,516	202	44	21.8%	29,434	1.48E+07	21,903	36,966
2	6/1	6/11	12,500	394	32	8.1%	149,621	6.05E+08	101,411	197,831
3	6/12	6/19	2,559	244	53	21.7%	11,989	2.08E+06	9,162	14,815
4	6/20	7/3	1,290	306	62	20.3%	5,896	4.54E+05	4,575	7,217
Total			0	0	0	18.0%	196,941	6.22E+08	148,046	245,835
							SE=	2.49E+04		



Appendix 2.–The 2008 daily smolt emigration from Afognak Lake depicting the timing of the flooding event and the average smolt emigration timing from 2003-2007.

Appendix 3.–Mean weight, length, and condition factor by age for sockeye salmon smolt sampled at Afognak Lake, 1987-2001, and 2003-2008.

		Age-1				Age-2			
Year	Sampling Period	n	Weight (g)	Length (mm)	Condition (K)	n	Weight (g)	Length (mm)	Condition (K)
1987	8-Jun	36	3.6	74.9	0.85	186	3.6	79.3	0.86
1988	15-Jun	202	4.1	77.9	0.90	0			
1989	15-Jun	208	4.1	76.8	0.91	2	5.2	78.0	1.10
1990	May 23-June 24	544	2.5	68.8	0.76	21	3.4	77.3	0.73
1991	May 13-June 26	1,895	3.1	72.9	0.78	176	3.9	78.3	0.81
1992	June 7-20	268	3.8	77.0	0.82	37	3.8	76.9	0.83
1993	May 24-30	274	3.0	72.7	0.78	21	3.3	74.8	0.79
1994	May 17-23	138	3.0	72.0	0.81	142	4.7	84.3	0.79
1995	May 31-June 13	394	2.8	69.4	0.84	5	3.6	78.8	0.74
1996	June 5-11	54	4.6	80.9	0.87	339	4.8	81.6	0.88
1997	May 24-30	76	4.3	81.7	0.78	122	4.4	82.1	0.79
1998	May 24-30	116	2.6	66.4	0.82	46	6.6	88.0	0.90
1999	May 31-June 6	96	2.8	74.6	0.66	98	2.1	66.6	0.69
2000	May 31-June 13	84	4.9	81.5	0.89	100	5.6	85.3	0.89
2001	June 11-13	44	7.0	90.1	0.93	17	5.8	85.6	0.92
2003	May 12-July 3	1,031	4.2	79.1	0.82	383	4.2	81.4	0.77
2004	May 11-July 3	1,370	3.6	75.7	0.80	81	3.6	78.7	0.74
2005	May 10-June 27	1,248	3.9	76.8	0.84	65	4.2	81.3	0.77
2006	May 16-June 29	765	3.0	70.8	0.83	202	3.8	79.6	0.75
2007	May 21 - July 2	960	2.6	70.4	0.75	129	3.4	76.5	0.74
2008	May 26 - June 28	169	3.4	75.9	0.76	164	4.0	81.7	0.73
2003-2007		5,374	3.5	74.6	0.81	860	3.8	79.5	0.75
2003-2008		5,543	3.5	74.8	0.80	1,024	3.9	79.9	0.75



Appendix 4.–Sockeye salmon smolt emigration timing from Afognak Lake, 2003-2008.

Appendix 5.–Temperatures (°C) measured at the 1-meter and near bottom strata in the Spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake 1989-2008.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	7.8	7.0	16.3	12.8	15.3	13.6
1990	9.4	8.3	14.8	13.6	11.9	11.4
1991	6.2	5.7	15.1	12.5	12.4	12.1
1992	10.0	8.9	15.5	13.9	11.1	11.0
1993	11.9	10.4	17.6	14.5	13.5	12.6
1994	10.8	8.8	15.5	13.5	10.2	9.7
1995	8.8	7.3	15.2	12.8	12.5	11.9
1996	11.5	9.7	15.2	13.9	11.1	10.5
1997	10.3	7.5	17.6	10.6	14.1	12.4
1998	7.9	7.7	14.3	13.0	11.8	11.6
1999	7.0	6.2	15.1	11.4	10.4	10.1
2000	9.7	8.7	15.0	13.1	10.1	10.0
2001	9.1	7.0	17.1	10.2	12.9	12.5
2002	10.0	7.8	16.0	10.8	9.3	9.2
2003	9.7	5.5	18.3	12.9	11.5	11.3
2004	9.2	8.2	15.1	11.7	13.1	12.9
2005	11.8	9.5	18.1	13.5	13.6	13.5
2006	9.2	8.0	15.8	12.5	12.6	12.5
2007	9.2	6.7	15.4	9.5	12.4	12.3
2008	8.6	6.9	14.7	13.3	11.9	11.4
Avg 1989-2007	9.4	7.8	15.9	12.5	12.1	11.6
Avg 1989-2008	9.4	7.8	15.9	12.5	12.1	11.6

Appendix 6.–Dissolved oxygen concentrations (mg L-1) measured at the 1-meter and near bottom strata in the Spring (May-June), summer (July-August), and fall (September-October) for Afognak Lake 1989-2008.

	Spring		Summer		Fall	
Year	Surface	Bottom	Surface	Bottom	Surface	Bottom
1989	11.7	11.2	10.3	9.2	13.1	10.3
1990	14.0	11.8	9.5	8.6	9.6	8.9
1991	12.6	11.1	10.9	8.2	10.5	9.4
1992	11.5	10.8	10.1	8.7	10.8	10.8
1993	10.9	9.8	9.5	7.5	10.5	10.1
1994	11.0	9.8	10.0	8.1	11.3	10.9
1995	11.4	11.3	10.0	8.4	10.5	9.8
1996	10.9	10.5	10.0	7.7	11.2	11.1
1997	10.5	10.7	9.0	4.6	10.2	7.6
1998	11.8	11.7	10.2	6.1	10.2	10.0
1999	11.9	11.5	9.6	6.2	10.9	10.4
2000	11.0	9.1	9.7	6.8	10.5	10.1
2001	9.7	9.6	9.3	4.7	9.0	8.1
2002	10.8	9.3	9.8	0.1	10.5	10.1
2003	12.0	11.1	9.2	5.5	18.0	10.3
2004	12.9	11.2	11.5	8.1	10.5	6.4
2005	10.8	10.2	9.5	5.1	9.5	8.7
2006	10.9	10.0	9.8	8.3	10.5	10.0
2007	11.4	10.8	9.2	6.6	10.6	9.9
2008	12.5	10.7	9.5	8.9	9.5	9.9
Avg 1989-2007	11.4	10.6	9.8	6.8	10.9	9.6
Avg 1989-2008	11.5	10.6	9.8	6.9	10.9	9.6

Appendix 7.–Average euphotic zone depth (EZD), light extinction coefficient (Kd), Secchi disk (SD) transparency, and euphotic volume (EV) for Afognak Lake, 1990-2008.

Year	EZD (m)	SD	K_d (m^{-1})	SD	Secchi (m)	SD	EV (10^6m^3)	SD
1990	7.47	2.46	-2.01	0.53	3.6	0.6	39.60	13.02
1991	8.36	2.40	-2.25	0.68	2.7	0.5	44.32	12.75
1992	9.39	2.79	-2.28	0.35	2.8	0.9	49.77	14.77
1993	9.27	2.23	-2.09	0.52	3.5	0.5	49.14	11.81
1994	7.73	1.45	-1.86	0.33	3.4	0.4	40.97	7.67
1995	7.56	1.18	-1.79	0.27	2.5	0.6	40.08	6.23
1996	8.19	1.53	-1.92	0.37	3.5	0.4	43.41	8.13
1997	6.15	1.75	-1.68	0.59	3.2	0.7	32.61	9.27
1998	7.64	0.82	-1.76	0.25	3.8	1.2	40.50	4.36
1999	9.12	2.67	-1.82	0.35	2.9	0.6	48.36	14.14
2000	9.93	1.65	-2.28	0.39	3.4	0.6	52.62	8.76
2001	10.87	3.24	-2.24	0.40	4.0	1.1	57.61	17.17
2002	10.15	0.69	-2.43	0.17	4.3	0.5	53.80	3.66
2003	9.91	1.11	-2.36	0.25	4.5	0.2	52.51	5.87
2004	10.27	2.57	-2.32	0.31	4.0	0.3	54.42	13.60
2005	9.77	0.64	-2.28	0.20	4.7	0.6	51.77	3.37
2006	9.18	1.05	-2.16	0.36	4.0	0.7	48.67	5.54
2007	9.36	1.27	-2.05	0.36	4.1	0.7	49.61	6.73
2008	9.10	1.40	-2.03	0.27	4.4	0.4	48.23	7.42
Avg 1990-2007	8.91	1.75	-2.09	0.37	3.61	0.63	47.21	9.27
Avg 1990-2008	8.92	1.73	-2.08	0.37	3.65	0.62	47.26	9.17

Appendix 8.–Summary of seasonal mean nutrient and algal pigment concentrations by station and depth for Afognak Lake, 1990-2008.

	Station	Depth	Total Phosphorus		Total filterable-P		Filterable reactive-P		Total Kjeldahl Nitrogen		Ammonia		Nitrate +Nitrate		Reactive Silicon		Organic Carbon		Chlorophyll *a*		Phaeophytin *a*	
Year		(m)	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD	(ug L^{-1})	SD
1990	1	1	4.5	1.5	2.9	4.2	3.7	1.7	128	16.5	8	3.0	40	29.1	3250	247.5	145	13.0	0.34	0.19	0.17	0.03
	1	16	5.1	2.3	1.3	1.3	2.8	1.1	118	22.7	10	4.2	65	29.1	3390	154.5	144	30.6	0.21	0.03	0.28	0.07
1991	1	1	5.0	2.8	3.2	0.6	2.3	0.4	151	22.6	11	1.8	57	21.3	2865	108.6	ND	ND	0.31	0.21	0.27	0.07
	1	14	4.6	1.5	6.0	3.5	4.5	3.2	138	12.3	14	5.0	70	23.2	2966	156.3	ND	ND	0.22	0.14	0.22	0.08
1992	1	1	3.8	0.5	4.1	2.5	3.1	2.4	135	13.9	3	1.7	62	26.1	3163	158.9	199	64.1	0.44	0.29	0.28	0.13
	1	24	3.9	1.7	4.0	3.2	2.6	1.7	127	12.8	10	4.1	93	23.1	3182	198.0	163	52.9	0.31	0.25	0.28	0.12
1993	1	1	4.5	0.8	3.7	1.3	2.8	0.5	148	18.5	5	2.2	49	30.4	3132	220.6	147	53.3	1.01	0.31	0.36	0.03
	1	25	4.9	1.3	8.5	11.7	6.8	9.9	136	17.3	19	10.1	98	31.7	3380	244.0	121	47.5	0.52	0.21	0.45	0.14
1994	1	1	5.7	0.7	4.5	3.3	3.6	2.3	160	23.8	3	1.7	40	21.4	2843	122.4	114	33.0	0.56	0.26	0.28	0.08
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.56	0.34	0.34	0.10
	1	26	5.3	1.1	4.8	3.9	4.2	3.2	160	17.7	15	9.7	74	23.8	3177	285.5	128	52.1	0.36	0.21	0.27	0.09
1995	1	1	8.7	2.7	3.0	1.5	2.0	1.1	168	21.6	9	14.1	66	22.1	1873	735.0	ND	ND	3.92	2.44	1.13	0.62
	1	17	8.1	2.0	1.9	1.1	1.1	0.4	187	47.1	35	44.3	45	35.0	2046	618.4	ND	ND	3.13	1.75	1.10	0.54
	2	1	7.4	2.1	2.1	1.2	1.7	1.0	169	31.0	9	14.0	54	33.2	1942	753.9	ND	ND	4.20	2.90	1.05	0.65
	2	11	7.2	1.7	2.2	2.0	1.6	1.1	157	26.0	16	17.4	52	34.1	2143	805.6	ND	ND	3.27	2.18	1.05	0.62
1996	1	1	9.2	2.6	3.4	0.7	2.8	0.3	161	34.0	18	13.9	40	29.2	2465	297.2	225	80.3	2.39	1.16	0.82	0.38
	1	18	8.2	2.7	2.4	0.7	2.2	0.3	161	56.5	36	37.6	51	27.8	2663	176.1	190	73.1	1.40	0.56	0.81	0.37
	2	1	8.8	2.6	2.7	0.8	2.2	0.4	160	37.3	8	14.6	41	25.9	2466	275.0	226	52.5	1.77	0.50	0.85	0.36
	2	11	8.4	2.8	3.4	1.6	2.9	1.3	147	41.3	29	24.5	50	25.9	2630	220.7	169	55.7	1.07	0.29	0.77	0.31
1997	1	1	7.3	1.9	2.7	1.0	2.6	0.9	155	33.9	14	14.2	22	23.9	2347	354.4	273	63.8	2.56	1.42	1.51	0.66
	1	18	7.2	1.5	2.6	0.5	2.3	0.4	194	68.6	64	53.3	55	14.5	2995	503.5	197	28.8	1.12	0.50	1.08	0.38
	2	1	6.9	1.7	3.6	1.8	3.1	1.5	156	37.8	13	15.8	17	21.8	2435	351.3	252	62.8	1.68	1.25	1.19	0.83
	2	13	6.5	1.4	2.8	1.9	2.3	0.8	148	38.7	21	12.4	30	20.1	2584	433.5	156	50.6	1.33	1.17	1.06	0.76

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Year	Station	Depth (m)	Total Phosphorus (ug L^{-1})	SD	Total filterable-P (ug L^{-1})	SD	Filterable reactive-P (ug L^{-1})	SD	Total Kjeldahl Nitrogen (ug L^{-1})	SD	Ammonia (ug L^{-1})	SD	Nitrate +Nitrate (ug L^{-1})	SD	Reactive Silicon (ug L^{-1})	SD	Organic Carbon (ug L^{-1})	SD	Chlorophyll *a* (ug L^{-1})	SD	Phaeophytin *a* (ug L^{-1})	SD
1998	1	1	9.0	1.7	3.3	0.8	1.9	0.0	193	7.7	21	13.9	38	15.9	2387	73.0	152	118.8	0.10	0.04	0.04	0.02
	1	18	7.5	ND	3.7	ND	1.9	ND	182	ND	25	ND	63	ND	2311	ND	36	ND	0.09	ND	0.03	ND
1999	1	1	17.7	18.3	8.6	10.2	6.8	10.0	247	147.2	36	42.6	124	35.2	2390	431.5	261	122.2	2.94	3.19	0.56	0.35
2000	1	1	9.5	4.3	3.1	1.6	1.8	1.6	57	36.6	19	12.5	72	36.1	ND	ND	ND	ND	2.43	1.46	1.10	0.80
2001	1	1	7.8	5.1	6.4	5.2	8.2	6.7	115	22.2	5	3.6	38	32.5	ND	ND	ND	ND	2.37	0.53	0.30	0.20
2002	1	1	6.4	2.3	4.5	3.1	1.5	0.9	131	15.4	5	2.5	27	18.8	ND	ND	ND	ND	1.36	0.14	0.30	0.20
2003	1	1	6.5	3.0	2.2	0.8	2.1	0.8	ND	ND	6	1.8	54	26.9	ND	ND	ND	ND	1.20	0.20	0.50	0.40
2004	1	1	6.2	3.5	4.3	3.2	2.0	0.7	169	103.8	9	2.8	61	31.5	2764	342.8	ND	ND	1.15	0.18	0.28	0.08
	1	18	5.9	2.3	6.2	8.3	3.5	3.5	ND	ND	19	13.2	80	28.4	2914	277.1	ND	ND	0.70	0.35	0.19	0.11
2005	1	1	11.4	4.4	7.6	3.6	3.6	3.1	161	45.6	4	2.0	41	34.8	2701	243.7	ND	ND	1.60	0.68	0.24	0.11
2006	1	1	7.2	4.3	2.2	1.6	2.3	1.1	97	59.6	7	1.7	28	30.8	ND	ND	ND	ND	1.92	0.32	0.50	0.09
2007	1	1	3.6	0.4	1.1	0.3	1.1	0.6	115	32.4	6	0.7	56	39.5	ND	ND	ND	ND	1.47	0.43	0.21	0.08
2008	1	1	3.8	1.1	2.3	1.5	1.6	0.9	113	28.6	6	0.6	65	42.3	ND	ND	ND	ND	1.22	0.66	0.58	0.37
Fertilization yrs.																						
1990-2000 Avg		1	7.7	3.4	3.9	2.5	3.0	1.9	155	34.2	13	11.0	55	26.4	2672	274.9	189	68.6	1.54	1.00	0.59	0.29
All years																						
1990-2007 Avg		1	7.5	3.2	3.8	2.3	2.9	1.8	149	38.1	10	8.6	49	27.9	2602	314.4	199	66.4	1.70	0.86	0.57	0.29
1990-2008 Avg		1	7.3	3.1	3.7	2.3	2.9	1.8	147	37.6	10	8.3	50	28.6	2602	314.4	199	66.4	1.68	0.85	0.57	0.30
Post-fertilization yrs.																						
2001-2007 Avg		1	7.0	3.3	4.0	2.5	3.0	2.0	131	46.5	6	2.2	43	30.7	2732	293.3	ND	ND	1.58	0.35	0.33	0.17
2001-2008 Avg		1	6.6	3.0	3.8	2.4	2.8	1.9	129	43.9	6	2.0	46	32.1	2732	293.3	ND	ND	1.54	0.39	0.36	0.19

Appendix 9.–Summary of seasonal mean water chemistry parameters by station and depth for Afognak Lake, 1990-2008.

	Station	Depth	Sp. Conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
Year		(m)	(umhos cm^{-1})	SD	(Units)	SD	(mg L^{-1})	SD	(NTU)	SD	(Pt units)	SD	(mg L^{-1})	SD	(mg L^{-1})	SD	(ug L^{-1})	SD
1990	1	1	41	1.7	6.8	0.1	6.3	0.5	0.8	0.4	14	3.4	2.9	1.4	0.4	0.3	121	24.3
	1	16	41	1.0	6.7	0.2	6.1	0.6	0.7	0.4	11	2.2	3.2	1.8	0.4	0.3	128	38.7
1991	1	1	38	0.8	6.7	0.1	10.4	7.8	0.9	0.3	13	0.8	2.1	0.3	0.8	0.5	210	31.1
	1	14	38	1.0	6.6	0.2	6.9	0.3	0.9	0.2	16	3.9	1.9	0.1	0.8	0.5	190	45.0
1992	1	1	35	1.2	6.6	0.2	5.8	1.0	0.9	0.5	12	3.4	2.5	0.9	0.6	0.3	157	9.3
	1	24	35	0.5	6.3	0.1	4.9	1.0	0.8	0.6	11	1.5	2.5	1.2	0.6	0.3	162	56.9
1993	1	1	37	1.0	6.6	0.1	7.5	2.7	0.5	0.1	7	7.5	2.2	0.4	1.3	1.1	104	34.9
	1	25	39	4.0	6.4	0.4	7.8	2.1	0.5	0.2	10	10.7	2.6	0.9	0.8	0.1	134	52.0
1994	1	1	39	6.5	6.6	0.2	6.2	2.0	1.1	0.8	5	3.2	2.2	0.9	0.6	0.2	141	44.0
	1	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	26	36	0.9	6.3	0.3	6.5	2.5	0.7	0.3	6	4.7	2.2	0.5	0.6	0.2	197	87.7
1995	1	1	60	5.6	6.6	0.2	9.8	1.0	2.0	0.8	11	2.6	3.7	1.4	1.3	0.4	85	45.6
	1	17	60	5.4	6.5	0.2	10.0	1.3	2.3	1.2	9	2.0	3.4	0.5	1.6	0.5	101	33.0
	2	1	58	4.9	6.6	0.2	9.7	1.1	1.9	0.9	11	4.3	3.2	0.3	1.1	0.3	87	55.9
	2	11	58	4.3	6.5	0.2	9.6	1.1	2.0	0.8	10	5.5	3.5	0.4	1.3	0.3	101	53.9
1996	1	1	56	1.5	6.7	0.2	10.5	0.7	1.4	1.0	10	2.5	3.2	0.5	1.3	0.2	54	25.9
	1	18	57	2.7	6.6	0.1	11.2	1.9	1.5	0.7	9	0.5	3.1	0.5	1.1	0.3	72	33.2
	2	1	56	1.4	6.7	0.1	10.7	1.0	1.2	0.6	9	1.3	3.1	0.5	1.1	0.3	54	25.7
	2	11	57	1.1	6.7	0.1	10.7	1.0	1.5	0.6	11	2.6	2.9	0.5	1.5	0.3	89	43.4

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Year	Station	Depth	Sp. Conductivity		pH		Alkalinity		Turbidity		Color		Calcium		Magnesium		Iron	
		(m)	(umhos cm^{-1})	SD	(Units)	SD	(mg L^{-1})	SD	(NTU)	SD	(Pt units)	SD	(mg L^{-1})	SD	(mg L^{-1})	SD	(ug L^{-1})	SD
1997	1	1	53	0.6	7.1	0.2	12.1	1.6	1.1	0.1	9	1.9	3.1	0.4	1.1	0.3	28	16.6
	1	18	58	6.7	6.8	0.2	13.9	3.5	1.7	0.4	10	0.8	2.9	0.5	1.7	1.1	68	37.7
	2	1	53	0.8	7.1	0.1	11.7	0.5	1.0	0.2	11	3.8	3.0	0.3	1.0	0.3	34	17.3
	2	13	53	0.5	7.0	0.1	11.9	0.3	1.3	0.5	10	3.0	2.9	0.3	1.0	0.3	44	25.8
1998	1	1	49	0.6	7.0	0.1	12.6	1.3	1.7	1.2	18	10.7	3.2	0.5	0.8	0.2	26	15.0
	1	18	48	ND	7.0	ND	11.8	ND	2.0	ND	11	ND	3.3	ND	1.0	ND	48	ND
1999	1	1	58	0	6.8	0.2	11.1	0.6	1.6	1.0	11	1.7	3.3	0.3	1.4	0.1	82	43.8
2000	1	1	ND	ND	7.1	0.2	8.7	2.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2001	1	1	ND	ND	7.2	0.4	10.1	2.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2002	1	1	ND	ND	7.2	0.5	10.1	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2003	1	1	ND	ND	6.9	0.1	9.8	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2004	1	1	ND	ND	6.9	0.1	11.4	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	1	18	ND	ND	6.8	0.1	10.9	0.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2005	1	1	ND	ND	6.8	0.1	10.9	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2006	1	1	ND	ND	6.8	0.1	11.3	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2007	1	1	ND	ND	6.8	0.1	10.9	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2008	1	1	ND	ND	6.7	0.2	11.4	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fertilization yrs.																		
1990-2000 Avg		1	49	2.1	6.8	0.2	9.5	1.7	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
All years																		
1990-2007 Avg		1	49	2.1	6.8	0.2	9.9	1.5	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
1990-2008 Avg		1	49	2.1	6.8	0.2	9.9	1.5	1.2	0.6	11	3.6	2.9	0.6	1.0	0.3	91	30.0
Post-fertilization yrs.																		
2001-2007 Avg		1	ND	ND	6.9	0.2	10.3	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2001-2008 Avg		1	ND	ND	6.9	0.2	10.7	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix 10.–Weighted mean zooplankton density, biomass, size by species for station 1 (1987-2008) and station 2 (1988-2008), Afognak Lake.

Station		*Epischura*			*Diaptomus*			*Cyclops*			*Bosmina*			*Daphnia*			*Holopedium*			TOTALS	
1	No.	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass	Size	Density	Biomass
Year	Samples	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)	(mm)	(no/m^2)	(mg/m^2)
1987	4	28,835	100	0.91	173	1	1.01	4,127	6	0.65	138,370	134	0.33	3,218	4	0.54	2,574	6	0.52	177,297	251
1988	4	22,360	77	0.91	0	0	-	3,185	5	0.69	106,462	104	0.33	962	2	0.71	1,228	3	0.53	134,197	191
1989	5	16,322	71	0.99	0	0	-	3,663	5	0.66	69,638	59	0.31	1,778	3	0.64	1,347	3	0.48	92,748	141
1990	7	15,378	60	0.95	7	0	0.90	9,987	16	0.68	155,051	134	0.31	3,392	5	0.61	4,944	9	0.47	188,759	224
1991	6	21,278	102	1.02	265	1	0.79	6,606	12	0.74	208,574	193	0.32	4,089	9	0.72	4,025	8	0.50	244,837	325
1992	7	23,468	104	0.99	485	1	0.88	4,807	8	0.68	106,832	108	0.33	5,513	13	0.74	3,306	6	0.45	144,411	240
1993	7	33,893	127	0.94	76	0	0.83	5,960	11	0.72	240,817	247	0.34	7,689	14	0.66	3,715	8	0.50	292,150	407
1994	8	23,713	66	0.85	1,844	7	0.98	10,231	17	0.69	257,749	256	0.33	9,621	18	0.66	7,271	13	0.48	310,429	377
1995	7	16,758	84	1.04	5,596	16	0.87	24,932	39	0.68	212,768	197	0.32	13,740	22	0.62	1,410	2	0.46	275,204	360
1996	5	42,112	223	1.06	191	0	0.49	11,614	19	0.69	350,806	378	0.34	16,072	44	0.78	2,909	5	0.47	423,704	670
1997	6	14,367	69	1.02	5,520	11	0.75	24,567	41	0.69	81,591	66	0.30	11,720	17	0.58	915	1	0.43	138,679	205
1998	4	15,672	62	0.96	1,088	5	1.05	2,070	3	0.67	169,971	144	0.31	10,881	14	0.56	5,441	8	0.42	205,123	236
1999	4	18,737	78	0.97	5,945	24	0.97	6,688	12	0.71	133,175	130	0.33	9,449	20	0.68	2,495	5	0.46	176,489	269
2000	5	57,643	180	0.88	8,121	44	1.09	10,743	16	0.66	114,297	126	0.35	5,042	9	0.64	1,408	2	0.46	116,722	188
2001	5	30,122	66	0.77	2,548	6	0.79	8,121	10	0.61	40,764	33	0.30	1,253	1	0.49	2,638	4	0.43	85,446	120
2002	4	8,174	21	0.82	1,009	3	0.92	6,380	7	0.56	38,256	36	0.32	2,935	3	0.51	557	1	0.41	57,311	71
2003	4	39,743	73	0.73	3,782	7	0.74	3,185	4	0.62	102,110	85	0.30	1,393	2	0.60	1,194	2	0.48	151,407	173
2004	5	23,206	37	0.69	510	1	0.86	6,374	8	0.62	58,598	52	0.31	11,472	16	0.58	2,771	5	0.48	102,931	119
2005	5	21,369	59	0.84	1,592	4	0.83	8,238	10	0.60	82,409	65	0.30	4,979	7	0.57	2,027	3	0.43	120,614	148
2006	5	29,565	92	0.88	3,450	10	0.85	9,915	20	0.76	76,518	61	0.30	8,408	11	0.56	6,348	11	0.46	134,204	205
2007	5	10,913	24	0.78	2,930	9	0.88	7,718	13	0.70	74,257	66	0.31	3,386	5	0.58	1,730	3	0.47	100,934	120
2008	5	16,561	45	0.84	823	2	0.83	2,670	3	0.61	66,762	55	0.30	4,231	7	0.62	3,079	6	0.49	94,126	119
1987-1989 Avg		22,506	83	0.94	58	0	1.01	3,658	5	0.67	104,823	99	0.32	1,986	3	0.63	1,716	4	0.51	134,747	194
1987-2007 Avg		24,458	85	0.90	2,149	7	0.87	8,529	13	0.67	134,239	127	0.32	6,523	11	0.62	2,869	5	0.47	174,933	240
1987-2008 Avg		24,100	83	0.90	2,089	7	0.87	8,263	13	0.67	131,172	124	0.32	6,419	11	0.62	2,879	5	0.47	171,260	234
2001-2007 Avg		23,299	53	0.79	2,260	6	0.84	7,133	10	0.64	67,559	57	0.31	4,832	6	0.56	2,466	4	0.45	107,550	136
2001-2008 Avg		22,457	52	0.79	2,081	5	0.84	6,575	9	0.64	67,459	57	0.31	4,757	6	0.56	2,543	4	0.46	105,872	134

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Appendix 10.–Page 2 of 2.

Station 2 Year	No. Samples	*Epischura* Density (no/m²)	*Epischura* Biomass (mg/m²)	*Epischura* Size (mm)	*Diaptomus* Density (no/m²)	*Diaptomus* Biomass (mg/m²)	*Diaptomus* Size (mm)	*Cyclops* Density (no/m²)	*Cyclops* Biomass (mg/m²)	*Cyclops* Size (mm)	*Bosmina* Density (no/m²)	*Bosmina* Biomass (mg/m²)	*Bosmina* Size (mm)	*Daphnia* Density (no/m²)	*Daphnia* Biomass (mg/m²)	*Daphnia* Size (mm)	*Holopedium* Density (no/m²)	*Holopedium* Biomass (mg/m²)	*Holopedium* Size (mm)	TOTALS Density (no/m²)	TOTALS Biomass (mg/m²)
1988	4	10,656	45	0.98	40	0	1.44	809	1	0.70	108,838	110	0.33	1,405	3	0.65	942	3	0.55	122,690	162
1989	5	10,306	35	0.90	0	0	-	1,261	2	0.66	48,235	40	0.30	420	1	0.63	553	1	0.46	60,775	79
1990	7	12,610	48	0.94	0	0	-	3,460	5	0.66	128,277	108	0.31	2,350	4	0.64	4,026	7	0.47	150,723	172
1991	6	19,285	80	0.97	1,274	4	0.89	4,277	8	0.74	154,341	132	0.31	3,347	6	0.65	5,083	10	0.49	187,607	240
1992	7	8,948	34	0.94	144	1	1.00	1,436	2	0.67	82,879	84	0.33	2,521	5	0.70	1,579	3	0.45	97,507	129
1993	7	19,033	70	0.93	773	1	0.69	3,882	5	0.62	175,106	157	0.32	2,570	5	0.67	3,988	7	0.47	205,352	245
1994	8	11,006	40	0.93	783	3	0.91	2,736	4	0.65	125,352	116	0.32	4,321	7	0.64	2,468	4	0.46	146,666	174
1995	7	12,193	44	0.92	1,168	4	0.94	9,054	11	0.61	111,525	98	0.31	8,902	12	0.58	1,152	1	0.4	143,994	170
1996	5	20,892	99	1.02	255	2	1.17	2,930	6	0.77	219,747	239	0.35	4,331	11	0.76	1,571	2	0.46	249,726	359
1997	6	13,677	57	0.97	3,468	7	0.75	3,822	5	0.64	86,060	63	0.29	9,652	13	0.56	924	1	0.41	117,601	146
2004	5	27,192	44	0.70	32	0	0.95	5,125	8	0.66	34,843	27	0.29	2,187	4	0.62	1,624	3	0.44	71,003	84
2005	5	22,282	60	0.83	0	0	-	2,850	4	0.63	49,992	37	0.29	815	2	0.73	900	1	0.38	76,839	104
2006	5	9,408	14	0.68	510	1	0.78	3,083	5	0.70	44,282	31	0.28	3,571	5	0.59	1,274	2	0.43	62,128	59
2007	5	16,269	63	0.95	1,141	4	0.93	6,693	12	0.71	57,065	49	0.31	934	1	0.55	2,049	4	0.50	84,151	133
2008	5	20,786	51	0.81	1,592	8	1.04	2,484	3	0.59	49,260	38	0.29	786	2	0.67	1,314	2	0.44	76,222	103
1988-2007 Avg		15,268	52	0.90	685	2	0.95	3,673	6	0.67	101,896	92	0.31	3,380	6	0.64	2,010	4	0.46	126,912	161
1988-2008 Avg		15,636	52	0.90	745	2	0.96	3,593	5	0.67	98,387	89	0.31	3,207	5	0.64	1,963	3	0.45	123,532	157